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DISCRIMINANT ANALYSIS OF SES XR-1D BROACH DATA.(U)
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DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Maryland 20084

DISCRIMINANT ANALYSIS OF SES XR-1D BROACH DATA

by

J. Garner

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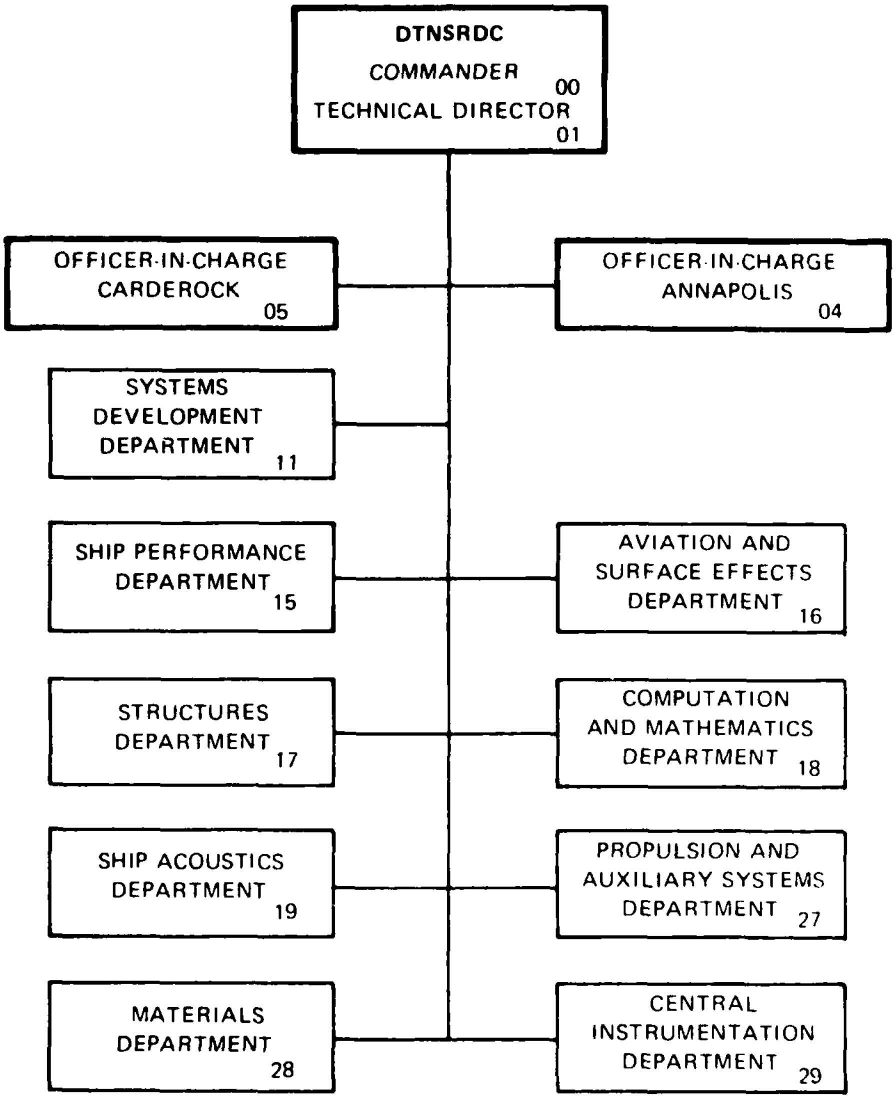
COMPUTATION, MATHEMATICS, AND LOGISTICS DEPARTMENT

DEPARTMENTAL REPORT

July 1981

DTNSRDC/CMLD-81/17

MAJOR DTNSRDC ORGANIZATIONAL COMPONENTS



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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: DTNSRDC/CMLD-81/17
2. GOVT ACCESSION NO.: AD-A104 581
3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): DISCRIMINANT ANALYSIS OF SES XR-1D BROACH DATA
5. TYPE OF REPORT & PERIOD COVERED: Final
6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): J. Garner
8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: David W. Taylor Naval Ship Research and Development Center, Bethesda, Maryland 20084
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 63534N, S0308SH, S0308SH001, 1824-006
11. CONTROLLING OFFICE NAME AND ADDRESS: Naval Sea Systems Command, Surface Effect Ships Project PMS 304
12. REPORT DATE: July 1981
13. NUMBER OF PAGES: 62
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)
15. SECURITY CLASS. (of this report): Unclassified

15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Pattern Recognition
Broaching
OLPARS
Discriminant Analysis
Control Theory

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Data from test runs of the Surface Effects Ship XR-1D test craft were collected and sorted into four performance classes with respect to the broaching (air ingestion) phenomenon. These classes included broach, no-broach and two intermediate conditions. Each data point was characterized by a twenty parameter measurement vector and the resulting 20-dimensional, four class data base was analyzed by the On Line Pattern Analysis and Recognition System (OLPARS) to determine the degree of separability of broach from

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S/N 0102-LF-014-6601

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

(Block 20 Continued)

no-broach as well as the measurements most meaningful in achieving this separability. The results show that broach is separable from no-broach with low error and that no measurement parameter other than draft had any clearly greater effect on results than any other parameter.

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ABSTRACT

Data from test runs of the Surface Effects Ship XR-1D test craft were collected and sorted into four performance classes with respect to the broaching (air ingestion) phenomenon. These classes included broach, no-broach and two intermediate conditions. Each data point was characterized by a twenty parameter measurement vector and the resulting 20-dimensional, four class data base was analyzed by the On Line Pattern Analysis and Recognition System (OLPARS) to determine the degree of separability of broach from no-broach as well as the measurements most meaningful in achieving this separability. The results show that broach is separable from no-broach with low error and that no measurement parameter other than draft had any clearly greater effect on results than any other parameter.

ADMINISTRATIVE INFORMATION

This report was written in The Computation, Mathematics and Logistics Department under the sponsorship of the Naval Sea Systems Command, Surface Effect Ship Project, Task Area Number S0308SH001, Project S0308SH, Program Element 63534N 63534N, Job Order 1-1824-006.

INTRODUCTION

Data from six test runs of the Surface Effects Ships XR-1D test craft were collected and separated according to four performance classes: normal or no-broach (Zone 0), full broach (Zone 3), and two intermediate stages of broach (Zone 1 and Zone 2). A broach is caused by air ingested into the water-jet propulsion system of the craft and is signalled by a sudden decrease in pump torque. The strip charts of the pump torque measurements taken during the test runs were visually scanned and all broach or partial broach conditions were noted along with their time of occurrence. Recorded data from the XR-1D's instrumentation plus the test logs then became the basis of twenty measurements taken for each broach and a certain number of non-broaches. The resulting four-class data base was analyzed with the On Line Pattern Analysis and Recognition System (OLPARS) on the CDC 6700 computer at the Computation, Mathematics and Logistics Department of DTNSRDC. This analysis determined linear separations of broach conditions from no-broach conditions and identified parameters most (or least) effective in achieving the separation.

DATA

Data were collected from six different test runs of the XR-1D test craft in the summer of 1977. From instrumentation aboard the craft and information from the test logs, a vector composed of twenty measurements was derived for each test point. A test point is a confirmed (Zone 1, Zone 2, or Zone 3) broach condition or a no-broach (Zone 0) occurring during a specifically determined time interval in a test run. The time slices were identified by visually scanning the readouts of the pump torque measurements and recording the time, duration, and class (Zone 1,2, or 3) of each broach occurring during test operations. A similar procedure was followed to identify a number of no-broach (Zone 0) conditions. Zone 3 is characterized by a full minimum of pump torque for a definite amount of time, and Zone 0 is characterized by a constant full torque. Zones 1 and 2 are intermediate levels. The distinction between zones, therefore, is subject to some variation resulting from personal interpretation. In these tests, all broach data points were measured and a number of no-broach data points, approximately equal to the number of Zone 3 data points, were included to complete the data set. The final distribution of test points (after some deletions due to incomplete measurements) is as follows:

Zone 0	:	152 points
Zone 1	:	200 points
Zone 2	:	276 points
Zone 3	:	147 points
Total	:	775 points

The twenty measurement parameters chosen to characterize the broach data points are listed in Table 1 in the order in which they appeared in the 20-dimensional measurement vectors. As indicated in Table 1, thirteen of the measurements are obtainable from on-board instrumentation which provides analog recordings of these parameter values. The actual test point value for each of these parameters was obtained by sampling the analog signal at 50 Hertz during the test point interval and averaging the values received. Parameters number 11 and numbers 16 through 20 were obtained from test logs, and parameter number 10 was obtained by visual observation of video tapes of the port inlet during the test point time slice.

The concern resulting from previous investigations[1*] into broach classification was that test data did not provide a sufficient number of broach data points to lend great confidence to any analytical findings. Consequently, in this test series, much effort was expended to include data for all broach conditions encountered during testing and also to include approximately as many Zone 0 no-broach data points as Zone 3 points. The resulting distribution of data points does indeed seem to represent the broach conditions well. However, new questions have arisen about the adequacy of the Zone 0 distribution, specifically whether the relative distribution of broach points to no broach points actually reflects the frequency of occurrence of these states in the normal operation of the craft. A more representative set of no-broach points probably would be larger than the current set and would also contain many

*A complete listing of references is given on page 32.

TABLE 1. MEASUREMENT PARAMETERS VECTOR ORDER

* 1. Craft speed (knots)
* 2. Pitch angle (deg.)
* 3. Pitch rate (deg./sec.)
* 4. Yaw rate (deg./sec.)
* 5. Roll angle (deg.)
* 6. Roll rate (deg./sec.)
* 7. Cushion pressure #3 (p.s.f.)
* 8. Port inlet velocity ratio (IVR)
* 9. Starboard IVR
10. Draft (inches)
11. Stern seal position (inches)
*12. Vertical center of gravity (VCG) acceleration (g)
*13. Total fan air flow (c.f.s.)
*14. Port nozzle angle (deg.)
*15. Starboard nozzle angle (deg.)
16. Gross weight (lbs.)
17. Longitudinal center of gravity (LCG) (ft.)
18. Sea state (0, 1, 2)
19. Heading (1=head, 2=beam, 3=follow, 4=quarter, 5=calm)
20. Turn or straight (1=T, 2=S)

* Obtained from on-board analog instrumentation

more points than the broach sets. The effect of a larger no broach data set on the results of this study is not known and depends on the degree of uniformity of the measurement set during no broach operation. Accordingly, future broach data sets should have a greater concentration of no-broach data points.

OLPARS

OLPARS (On Line Pattern Analysis and Recognition System)[2] is an interactive computer graphics system available on the CDC 6700 computer at the Computation, Mathematics and Logistics Department. It allows the user to examine two-dimensional projections of multidimensional data, cluster the data, and draw piecewise linear discriminants.

ANALYSIS

MEASUREMENT EVALUATION

The OLPARS analysis of this broach data set initially encountered data formatting problems which were avoided by scaling the broach data set to obtain a uniform order of magnitude for all measurement components; specifically, the fan flow measurement was divided by 100 and the weight by 1000.

An OLPARS discriminant vector analysis of half of the data set using all twenty dimensions (measurements), yielded the following linear discriminant function:

$$f(x) = -.0159x_1 + .0162x_2 + .0115x_3 - .0499x_4 - .0126x_5$$
$$+ .0086x_6 - .0120x_7 + .6930x_8 - .6913x_9 + .0149x_{10}$$
$$+ .0223x_{11} + .0251x_{12} - .0745x_{13} - .0188x_{14} - .0130x_{15}$$
$$+ .0368x_{16} + .0733x_{17} - .1456x_{18} - .0053x_{19} + .0548x_{20}$$
$$- 1.5097 = 0$$

where $\bar{x} = (x_1, x_2, \ldots, x_{20})$ is the 20-dimensional measurement vector and $f(\bar{x})>0$ for no broach vectors and $f(\bar{x})<0$ for broach vectors. This discriminant, when tested against the remaining half of the data set exhibited the following classification results:

percentage of Zone 0 classed as broach (Zone 0 false alarm):	7.9%
percentage of Zone 1 classed as broach (Zone 1 false alarm):	45%
percentage of Zone 2 classed as no broach (Zone 2 error) :	19.6%
percentage of Zone 3 classed as no broach (Zone 3 error) :	5.6%

These results indicated that the different zones were at least partially separable, and further analysis was pursued to improve the classification rates and identify those measurement parameters having the greatest effect on results.

Subsequent analysis of this broach data set included the computation of histograms for each parameter in each broach zone, examination of covariance and eigen vector data, and the OLPARS analysis of coordinate plots of pairs of measurement parameters. (See the accompanying Appendixes.) Discussion with representatives of the Surface Effect Ships Project (Codes PMS-304-221, 1602, and 1630) about the physical meaning of each parameter and the test conditions resulted in reducing the number of parameters to be considered to fourteen by excluding the port and starboard IVR's, the VCG acceleration, weight, LCG, and sea state parameters. The sea states in the data set were all 0, 1, and 2, and it was felt

they varied too little and the measurement at that level was too subjective to be of much importance. The IVR's were judged to be directly dependent on the pump torques - the measurements used to manually isolate the broaches - and, as such, were supplemental effects of broaching rather than possible indicators. The weight, LCG, and VCG were considered to be dependent and non-controllable and, therefore, not meaningful for broach prediction. The fourteen remaining parameters, listed in Table 2, were then subjected to a series of discriminant analysis procedures in an attempt to identify the hierarchy of sensitivity among the parameters to broach/no broach classification.

SENSITIVITY ANALYSIS WITH OLPARS

OLPARS allows the user to visually examine two-dimensional projections of data in addition to obtaining computational results. Using the set of fourteen meaningful parameters listed in Table 2, OLPARS can easily supply a linear discriminant with associated false alarm and error rates. A reasonable discriminant for this broach data set in these fourteen measurements (dimensions) was found to be

$$\begin{aligned} f(x) = & - .1465x_1 + .0005x_2 - .5188x_3 - .0645x_4 - .1447x_5 \\ & - .0662x_6 + .2454x_7 + 0.\ x_8 + 0.x_9 + .3990x_{10} \\ & + .2700x_{11} + 0.\ x_{12} - .05909x_{13} + .1027x_{14} + .1205x_{15} \\ & + 0.\ x_{16} + 0.\ x_{17} + 0.x_{18} + .1146x_{19} - .0126x_{20} \\ & - 8.8143 = 0 \end{aligned}$$

where $x = (x_1, x_2, \ldots x_{20})$ is the full 20-dimensional measurement vector, as before, and zero coefficients are attached to those measurement components not being considered. Once again f(x) is positive

TABLE 2. REDUCED SET OF MEANINGFUL PARAMETERS

1. Craft speed (kts)
2. Pitch angle (deg.)
3. Pitch rate (deg./sec.)
4. Yaw rate (deg./sec.)
5. Roll angle (deg.)
6. Roll rate (deg./sec.)
7. Cushion pressure #3 (p.s.f.)
10. Draft (inches)
11. Stern seal position (inches)
13. Total fan air flow (c.f.s.)
14. Port nozzle angle (deg.)
15. Starboard nozzle angle (deg.)
19. Heading
20. Turn or straight

for no broach and negative for broach and had the following classification scores when tested on a holdout set of vectors different from the set used to generate the discriminant:

Zone 0 false alarm rate:	50%
Zone 1 false alarm rate:	78%
Zone 2 error rate :	8.7%
Zone 3 error rate :	1.4%

These errors combine to make a 35.6% combined error rate (or error of .356). Figure 1 shows a graph of the confidence intervals associated with this discriminant function and its error. For example, statistical computations show there is a .95 probability that the true combined error for this discriminant lies in the interval (.356 - .048 , .356 + .048) = (.308 , .404). That is, there is a 95% confidence that the true combined error for this discriminant is between .30 and .40. The confidence interval graph is, therefore, an indication of the reliability of both the discriminant and the testing procedure.

Expected test set error rate (interval center) = .356
Number of samples = 387

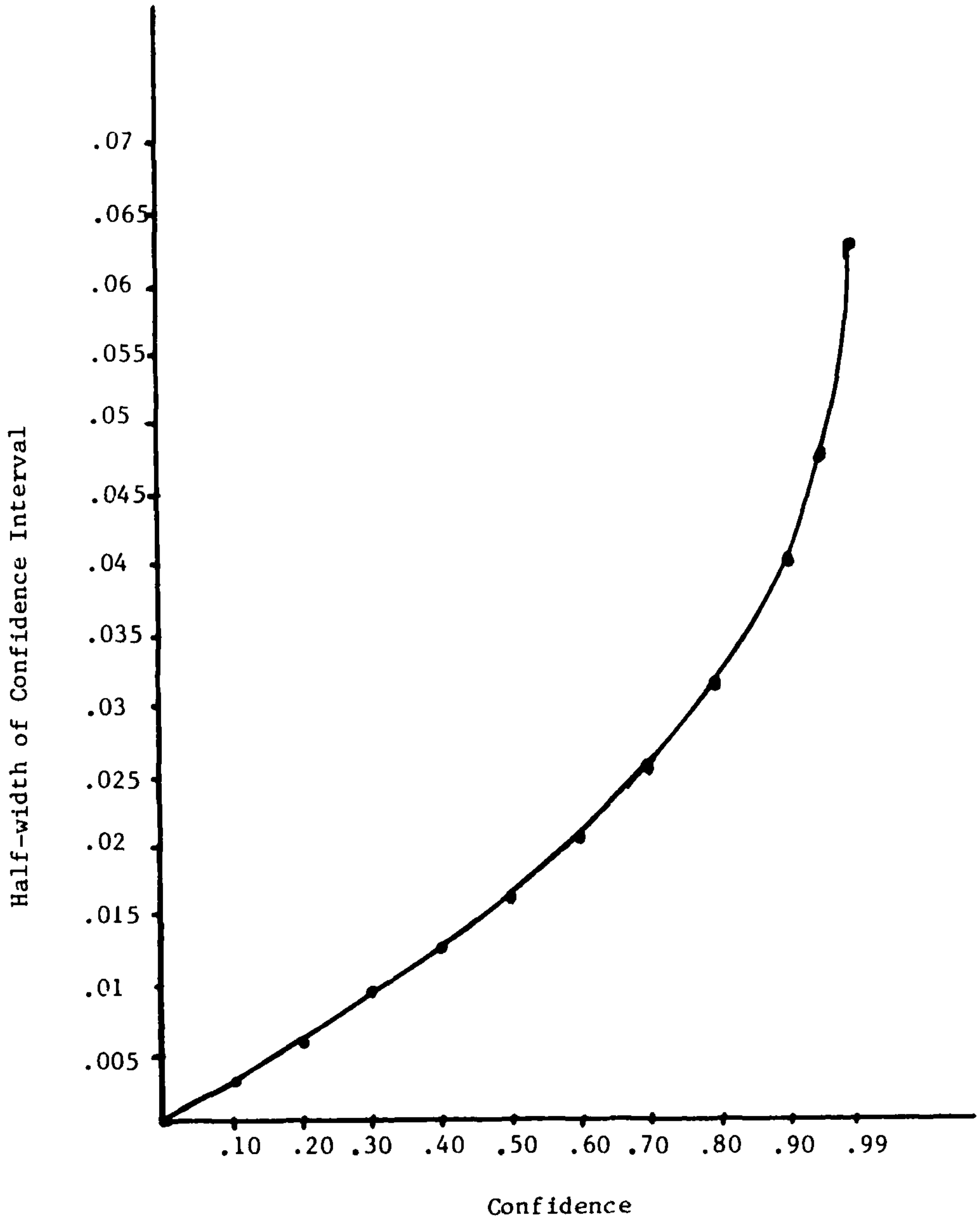


Fig. 1 Confidence Interval Graph
(14 Dimensions. Zone 1 considered No Broach)

At this point it should be noted that, during the course of this analysis, Zone 1 broaches were not classed in the same undesirable category as those in Zones 2 and 3. It was decided that Zone 1 broaches were not an entirely unacceptable operating condition and so most of the analysis was directed at separating Zone 0 from Zones 2 and 3, regardless of how Zone 1 was partitioned. In computing classification results, Zone 1 data were considered essentially no-broach and consequently false alarm rates, i.e., the percentage of Zone 1 data called broach, were listed for Zone 1. Zone 1 is by nature a type of broach and so it may not be entirely undesirable to have a large percentage of Zone 1 called broach by the discriminant function. In light of this, the above results may be interpreted slightly differently in the sense of separating Zone 0 from Zones 1, 2, and 3. In this case, the complement of the above Zone 1 false alarm rate becomes the Zone 1 error rate, with the following results:

Zone 0 false alarm rate	:	50%
Zone 1 error rate	:	22%
Zone 2 error rate	:	8.7%
Zone 3 error rate	:	1.4%

Figure 2 shows the confidence interval graph for this case where the combined error now is .211.

For the purpose of reporting results, the above discriminant was selected as the 14-dimensional basis for comparison with other discriminants. It is important to note how this function is created. The discriminant vector plot option in the structural analysis section of OLPARS computes two orthogonal vectors to define a discriminant vector

Expected test set error rate (interval center) = .211
Number of samples = 387

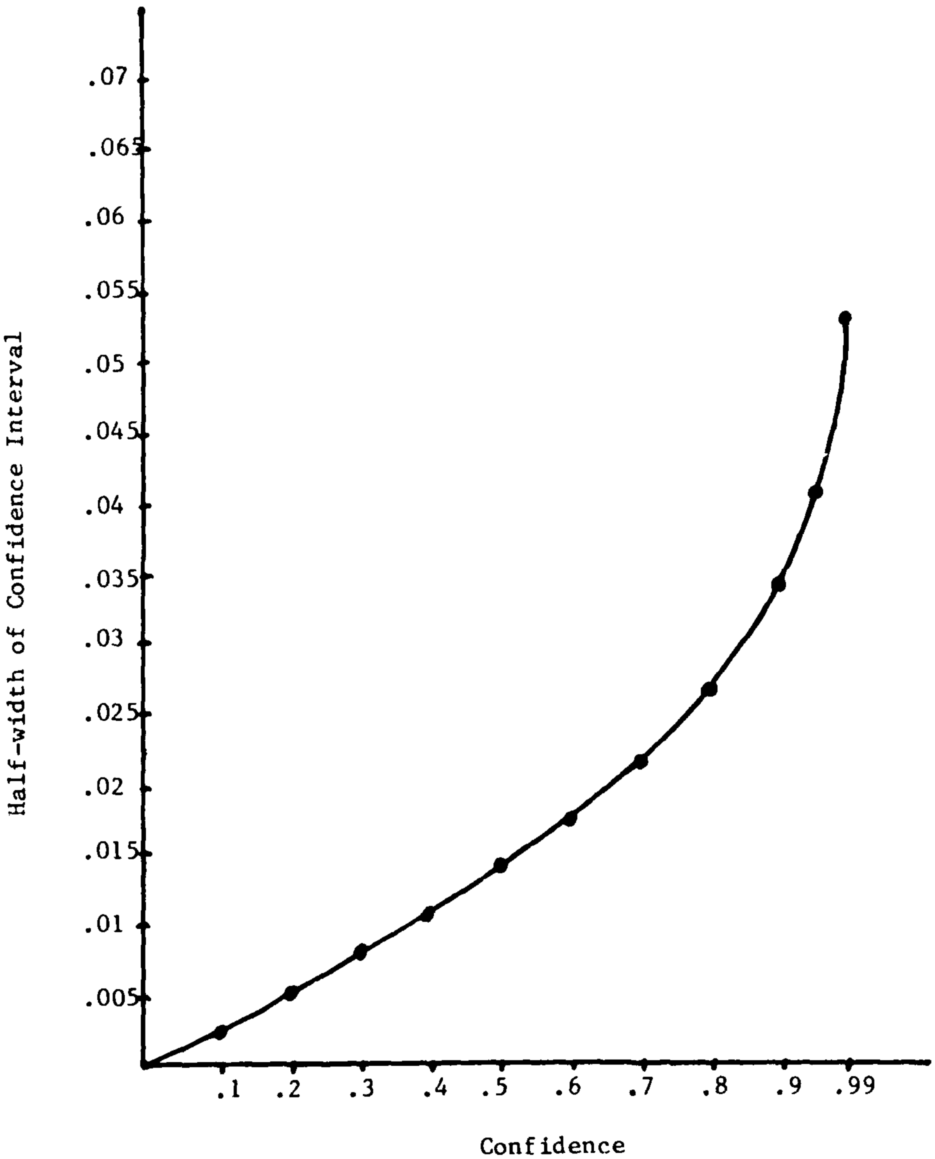
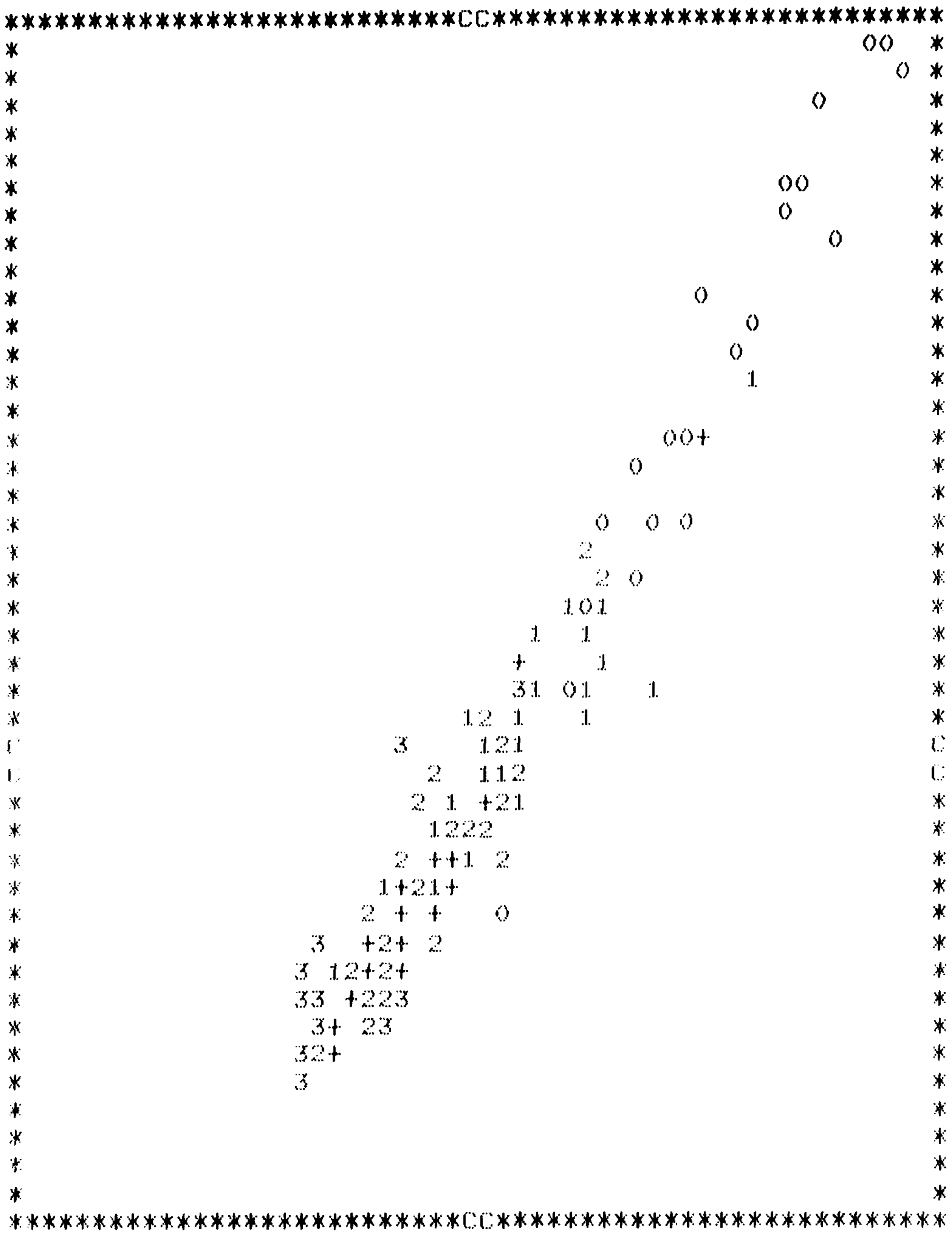


Fig. 2 Confidence Interval Graph
(14 Dimensions. Zone 1 considered Broach)

plane. This is a two-dimensional plane in which projected data, divided into two classes, have the properties that the spread of points within a class is minimized and the spread between classes is maximized. These properties make this an ideal plane in which to separate the two classes. Figure 3 shows the discriminant vector plane display for the 14-dimensional data set.



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DISCRIMINANT VECTORS     D 0/D 3                 SERIAL PAGE
  MISS184                                          1 OF  1
DISPLAY SCALE=    231.7754   X-AXIS CENTER=    -20.63
                             Y-AXIS CENTER=    -31.56
```

Fig. 3 OLPARS Discriminant Vector Plot
for 14 Dimensional Case

There is some separation of classes and, for example, one can draw any number of lines separating (in general) Zones 2 and 3 from Zone 0, each with a certain degree of error. Obviously, the zones are not completely separable; there is overlap. Here, in the OLPARS analysis, the user may select the OLPARS generated Fisher discriminant or position the line (from which the discriminant function is calculated) in the best place for the results desired (Figure 4). What exactly is the best place may ultimately depend on the false alarm and error rates achieved by the associated discriminant and these scores cannot be estimated until the discriminant is tested against the proper holdout sets of data in the Logic Evaluation Section of OLPARS. Consequently, there is a degree of subjectivity connected with the placement of the discriminant plane.

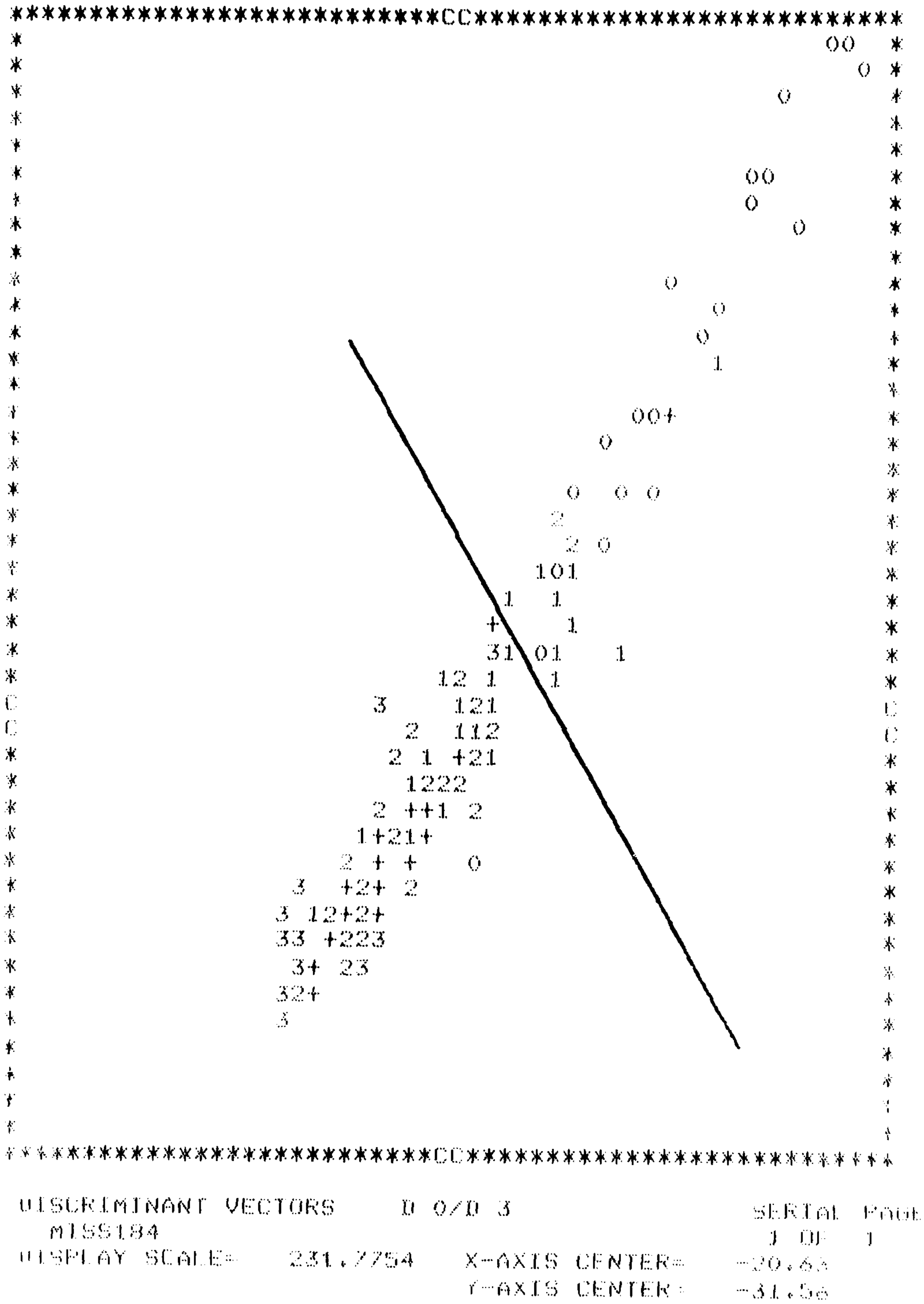

Fig. 4 OLPARS 14 Dimensional Discriminant Vector Plot with Partition

The sensitivity analysis procedure using OLPARS consisted of obtaining a discriminant vector for each case resulting from the current n dimensions considered n-1 at a time. For example, using fourteen dimensions results in fourteen thirteen-dimensional cases. Each case is run separately on the same analysis set (of data) and the resulting discriminant is tested separately on the same "holdout set" (data not used to generate the discriminant). In each case, the separability of the broach and no-broach zones is indicated by the classification scores of the resulting discriminants and also by visual observation of the data point scatter in the OLPARS discriminant vector plot. Since the only change in each case is the deletion of one measurement parameter and the reintroduction of another parameter, the separability evaluations are judgments on the meaningfulness or information content of the absent parameter. The worst separability would arise when the most meaningful parameter is excluded from the measurement set and the smallest decrease in separability would result when the least meaningful parameter is excluded. By carefully examining the separabilities achieved by the OLPARS discriminant vector plot for each of the fourteen thirteen-dimensional cases, the least meaningful parameter can be selected and eliminated from the measurement set. The procedure can be repeated for each of the thirteen twelve-dimensional cases and so on until only one parameter (the most significant) remains. In such a manner, a ranking of the significance of the measurement parameters can be achieved.

Two of the fourteen measurements are the turn/straight indicator and the heading indicator. Since these are non-continuous measurements

that easily partition the data set, they were set aside with the intention of developing separate discriminants for each of their possible values. The sensitivity analysis proceeded on the remaining twelve-dimension space. Table 3 shows the dimension reduction sequence with all discriminants and their false alarm (Zones 0 and 1) and error (Zones 2, 3) rates. In some cases, there was little difference between two parameters and both were dropped in one step. In every case, parameter number 10, "draft", seemed the most important. The significance of the draft parameter is substantiated by comparisons of the measurement parameter histograms and by the fact that the errors for any of the multidimensional discriminants are not far from the errors achievable by the "draft" histogram alone.

TABLE 3 - SENSITIVITY ANALYSIS

(Separate Zone 0 from Zones 2, 3
Analysis Set=ONE PAGE, Test Set=TEST1PAGE)

ID DATE/NO		# DIM.	MEASUREMENT NUMBERS	FALSE ALARM RATE Zone 0	Zone 1	ERROR RATE Zone 2	Zone 3
1/24	#1.1	12	1-7, 10, 11, 13, 14, 15	36	79	9.4	6.1
	#1.2	12	1-7, 10, 11, 13, 14, 15	27	60	17.3	12.2
	#2	11	1-7, 10, 11, 13, 14	34	63	14.5	7.0
	#3	11	1-7, 10, 11, 13, 15	33	63	14.0	7.0
	#4	11	1-7, 10, 11, 14, 15	44	72	8.9	2.6
	#5	11	1-7, 10, 13, 14, 15	30	67	10.8	7.8
	#6.1	11	1-7, 11, 13, 14, 15	54	88	8.4	13.0
	#6.2	11	1-7, 11, 13, 14, 15	60	90	4.7	7.8
	#7	11	1-6, 10, 11, 13, 14, 15	37	76	9.4	8.7
	#8	11	1-5, 7, 10, 11, 13, 14, 15	37	79	8.4	6.1
	#9	11	1-4, 6, 7, 10, 11, 13, 14, 15	37	79	9.4	6.1
	#10.1	11	1-3, 5-7, 10, 11, 13, 14, 15	36	72	9.8	7.0
	#10.2	11	1-3, 5-7, 10, 11, 13, 14, 15	59	90	2.8	3.5
	#10.3	11	1-3, 5-7, 10, 11, 13, 14, 15	36	72	9.8	7.8
	#11	11	1, 2, 4-7, 10, 11, 13, 14, 15	42	78	7.5	4.4
	#12	11	1, 3-7, 10, 11, 13, 14, 15	37	74	12.2	6.1
	#13	11	2-7, 10, 11, 13, 14, 15	44	83	11.2	2.6
2/17	#1	10	2-7, 10, 11, 14, 15	35	66	15.9	5.2
	#2	9	2-7, 10, 11, 14	44	78	13.1	4.4
	#3	9	2-7, 10, 11, 15	45	80	11.2	4.4
	#4	9	2-7, 10, 14, 15	41	70	15.4	4.4
	#5	9	2-7, 11, 14, 15	63	86	16.4	13.0
	#6	9	2-6, 10, 11, 14, 15	35	64	18.7	4.4
	#7	9	2-5, 7, 10, 11, 14, 15	44	76	11.2	1.7
	#8	9	2-4, 6, 7, 10, 11, 14, 15	43	76	11.7	3.5
	#9	9	2, 3, 5-7, 10, 11, 14, 15	41	73	13.1	4.4
	#10	9	2, 4-7, 10, 11, 14, 15	40	69	15.0	4.4
	#11	9	3-7, 10, 11, 14, 15	44	77	12.2	2.6

ID DATE/NO		# DIM.	MEASUREMENT NUMBERS	FALSE ALARM RATE Zone 0	Zone 1	ERROR RATE Zone 2	Zone 3
2/24	#1	9	2-5, 7, 10, 11, 14, 15	42	72	11.7	1.7
	#2	8	2-5, 7, 10, 11, 14	44	77	12.6	2.6
	#3	8	2-5, 7, 10, 11, 15	40	71	13.6	2.6
	#4	8	2-5, 7, 10, 14, 15	40	71	14.0	1.7
	#5	8	2-5, 7, 11, 14, 15	80	92	10.3	8.7
	#6	8	2-5, 10, 11, 14, 15	44	75	13.1	1.7
	#7	8	2-4, 7, 10, 11, 14, 15	48	81	9.4	1.7
	#8	8	2, 3, 5, 7, 10, 11, 14, 15	45	76	9.8	1.7
	#9	8	2, 4, 5, 7, 10, 11, 14, 15	49	81	7.9	1.7
	#10	8	3-5, 7, 10, 11, 14, 15	43	76	11.2	1.7
2/27	#1	7	3, 4, 5, 7, 10, 14, 15	41	71	13.6	1.7
	#2	6	3, 4, 5, 7, 10, 14	45	79	11.7	1.7
	#3	6	3, 4, 5, 7, 10, 15,	50	80	12.6	4.4
	#4	6	3, 4, 5, 7, 14, 15	57	64	39.7	33.0
	#5.1	6	3, 4, 5, 10, 14, 15	44	74	13.5	1.7
	#5.2	6	3, 4, 5, 10, 14, 15	42	72	13.1	3.5
	#6	6	3, 4, 7, 10, 14, 15	43	75	13.1	1.7
	#7	6	3, 5, 7, 10, 14, 15	42	72	12.6	1.7
	#8	6	4, 5, 7, 10, 14, 15	49	86	7.9	1.7
2/28	#1.1	5	4, 7, 10, 14, 15	48	85	7.0	1.7
	#1.2	5	4, 7, 10, 14, 15	47	82	10.1	2.6
	#2	4	4, 7, 10, 14	46	80	10.3	2.6
	#3	4	4, 7, 10, 15	42	74	17.3	3.5
	#4	4	4, 7, 14, 15	76	90	10.3	7.8
	#5	4	4, 10, 14, 15	34	59	20.1	5.2
	#6	4	7, 10, 14, 15	45	77	11.2	1.7
3/1	#1	4	7, 10, 14, 15	41	74	13.5	2.6

ID DATE/NO	# DIM.	MEASUREMENT NUMBERS	FALSE ALARM RATE Zone 0	Zone 1	ERROR RATE Zone 2	Zone 3
#2	3	7, 10, 14	41	72	13.5	4.4
#3	3	7, 10, 15	40	70	16.4	2.6
#4	3	7, 14, 15	68	86	15.4	12.2
#5	3	10, 14, 15	28	50	22.0	5.2
3/1.1 #1	3	10, 14, 15	27	48	24.7	6.1
#2	2	10, 14	34	61	24.3	6.1
#3	2	10, 15	29	54	21.5	5.2
#4	2	14,15 no apparent separation	x	x	x	x
H – #1	1	10	23	43	28.0	11.0
#2	1	10	33	61	19.0	6.0
#3	1	10	48	82	10.0	3.0

The order in which the parameters were dropped in the dimension reduction process was

1. Speed (1), total fan air flow (13)
2. Roll rate (6)
3. Pitch angle (2), stern seal position (11)
4. Pitch rate (3), roll angle (5)
5. Yaw rate (4)
6. Cushion pressure (7)
7. Port and starboard nozzle angles (14, 15)

At the top of this list are the least meaningful parameters for achieving separability. The least significant were found to be "speed" and "total fan air flow", both of which were expected to have greater effect on the decision process.

Table 4 shows the best (in a subjective sense) results from individual discriminants at each stage of dimensional reduction. This table will give some impression of the trade-offs in separability that are encountered in a process of this kind. Unfortunately, although these functions are the best among many considered, they need not be best in the sense of being most suited for the operational efficiency of the craft. For example, it may be operationally beneficial to shift the discriminant to gain better Zone 2 error rates at the expense of more false alarms. This question has not been addressed by this study.

TABLE 4 - "BEST" DISCRIMINANTS IN DIMENSIONAL REDUCTION PROCESS

# DIM.	FUNCTION ID	FALSE ALARM RATE Zone 0	FALSE ALARM RATE Zone 1	ERROR RATE Zone 2	ERROR RATE Zone 3
20	11-18-5	7.9	45	19.6	5.6
19	3-9-4	12	36	25.7	20.9
14	12-14-10	50	78	8.7	1.4
12	1-24-1.2	27	60	17.3	12.2
11	1-24-5	30	67	10.8	7.8
10	2-17-1	35	66	15.9	5.2
9	2-17-6	35	64	18.7	4.4
8	2-24-4	40	71	14.0	1.7
7	2-27-1	41	71	13.6	1.7
6	2-27-7	42	72	12.6	1.7
5	2-28-1.1	48	85	7.0	1.7
4	2-28-5	34	59	20.1	5.2
3	3-1.1-1	27	48	24.7	6.1
2	3-1.1-3	29	54	21.5	5.2
1	H-1	23	43	28.0	11.0

The tabulated results for the five-dimensional case show very little degradation from those of the fourteen-dimension results. This suggests that the measurements deleted to obtain the five dimensions have little significant effect on the classification performance of the system. Likewise, the results for the two dimensions agree closely with the results for four dimensions. Table 4 contains results for one discriminant not based on the "draft" measurement parameter and that is the 19-dimension case. Comparison of this case with the twenty-dimension case gives an indication of the degradation induced by ignoring the "draft" parameter. The results from the twenty-dimension case must be qualified since they are achieved by including the six parameters judged to measure only supplemental effects of broach and not valid, controllable phenomena for prediction.

As a basis for further comparison, the confidence interval graph for the two-dimensional discriminant listed in Table 4 is shown in Figure 5. The combined error for separating Zones 0 and 1 from Zones 2 and 3 is .281. The confidence interval graph indicates a slightly greater confidence in the accuracy of this error estimate than in the estimate for the fourteen-dimensional discriminant (Figure 1). The graph, therefore, supports the conclusion that there has been little degradation in discriminating power from fourteen dimensions to two dimensions.

Expected test set error rate (interval center) = .281
Number of samples = 604

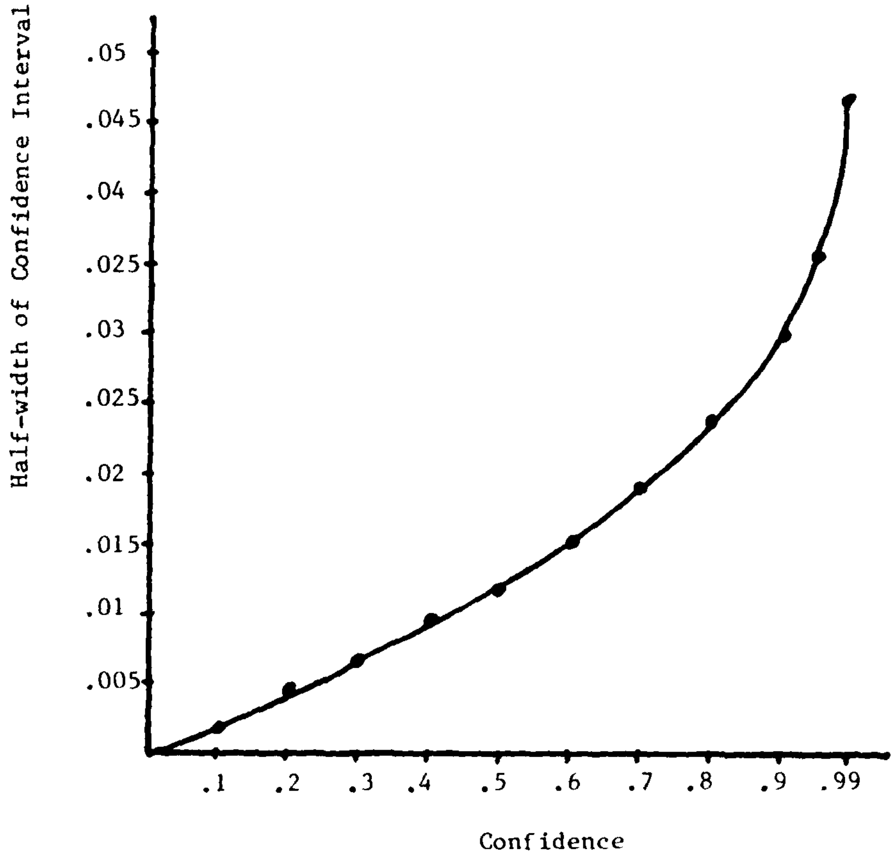

Fig. 5 Confidence Interval Graph
(2 Dimensions)

It is important to note that discriminants with very low error rates (for Zone 3) on this data set have the higher false alarm rates (for Zone 0). This results from the inherent overlap of Zone 3 and Zone 0 data points and the placement of the discriminant plane. In general, during the OLPARS analysis, the planes were drawn to obtain the best error rates without causing great increases in false alarm rates for each Zone 3 point added to the proper side of the plane. A more balanced set of error and false alarm rates can always be achieved by positioning the discriminant plane more towards the center of the overlap in the OLPARS discriminant vector plot display. (See Figure 4)

MULTIPLE DISCRIMINANTS

The two parameters deleted prior to the OLPARS analysis of twelve dimensions were the "heading" and "turn/straight" indicators. These were set aside because of the non-continuous nature of the arbitrarily assigned numeric values and the ease with which they lent themselves to the use of multiple discriminants. Table 5 lists scores for discriminants created by, in one case, sorting the data set between "turn" data and "straight" data and, in the other case, sorting according to "heading". The principal data sets obtained from the heading parameter were those for "calm", "head", and "following" conditions. Some measurements existed in the data set for "quarter" and "beam" seas, but it was felt these sets were not large enough to give reliable results. When results are compared with those achieved by the twelve-dimensional discriminant of Table 4, and when it is assumed that results for "quarter" and "beam"

data are not significantly different, it can be seen that a set of discriminants based on heading can improve error rates slightly. Separate discriminants for "turn" and "straight", on the other hand, do not have much effect. This may be due to the low sea states of all points in this data set; sea states never exceeded sea state two. It seems reasonable to expect the distinction between "turn" and "straight" to have more significance in higher sea states.

Figure 6 shows the confidence interval graph for the composite discriminant described in A.1 of Table 5. The total composite error is .261 and the graph of confidence intervals for this case is very similar to that for the two dimensional discriminant shown in Figure 5.

TABLE 5. MULTIPLE DISCRIMINANTS BASED ON HEADING AND TURN STRAIGHT

A. Composite results separating Zones 0, 1 from Zones 2, 3 using separate discriminants for HEAD, FOLLOW, and CALM conditions of heading parameter.

1. Including Turn/Straight measurement (13 dimensions):

	False Alarm		Error	
	Zone 0	Zone 1	Zone 2	Zone 3
HEAD	.28	.60	.16	.044
FOLLOW	.22	.57	.22	.25
*CALM	.20	.37	.062	.00
COMPOSITE	.24	.51	.16	.11

* Note: CALM results are the same as in A.2. since there is no Turn data for CALM.

2. Not including Turn/Straight measurement (12 dimension):

	False Alarm		Error	
	Zone 0	Zone 1	Zone 2	Zone 3
HEAD	.13	.42	.28	.13
FOLLOW	.35	.69	.16	.19
*CALM	.20	.37	.062	.00
COMPOSITE	.22	.47	.19	.13

* Note: CALM results are the same as in A.1. since there is no Turn data for CALM.

B. Composite results for separating Zones 0, 1 from Zone 2, 3 using separate discriminants for HEAD, FOLLOW, and CALM but with Zone 1 data not used in constructing discriminants.

1. Including Turn/Straight (13 dimension)

	False Alarm		Error	
	Zone 0	Zone 1	Zone 2	Zone 3
HEAD	.31	.61	.12	.067
FOLLOW	.26	.88	.12	.17
CALM	.23	.37	.031	.10
COMPOSITE	.27	.60	.10	.11

2. Not including Turn/Straight (12 dimensions)

	False Alarm		Error	
	Zone 0	Zone 1	Zone 2	Zone 3
HEAD	.33	.65	.12	.067
FOLLOW	.29	.86	.12	.11
CALM	.23	.37	.031	.10
COMPOSITE	.28	.61	.10	.089

C. Composite results separating Zones 0, 1 from 2, 3 using separate discriminants for Turn and Straight. (Zone 1 data not used in constructing discriminants)

1. Including heading measurement parameter (13 dimensions)

	False Alarm		Error	
	Zone 0	Zone 1	Zone 2	Zone 3
TURN	.40	.82	.11	.15
STRAIGHT	.37	.64	.098	.084
COMPOSITE	.37	.66	.10	.10

2. Not including heading measurement (12 dimensions)

	False Alarm		Error	
	Zone 0	Zone 1	Zone 2	Zone 3
TURN	.32	.59	.25	.15
STRAIGHT	.30	.58	.13	.084
COMPOSITE	.30	.58	.16	.10

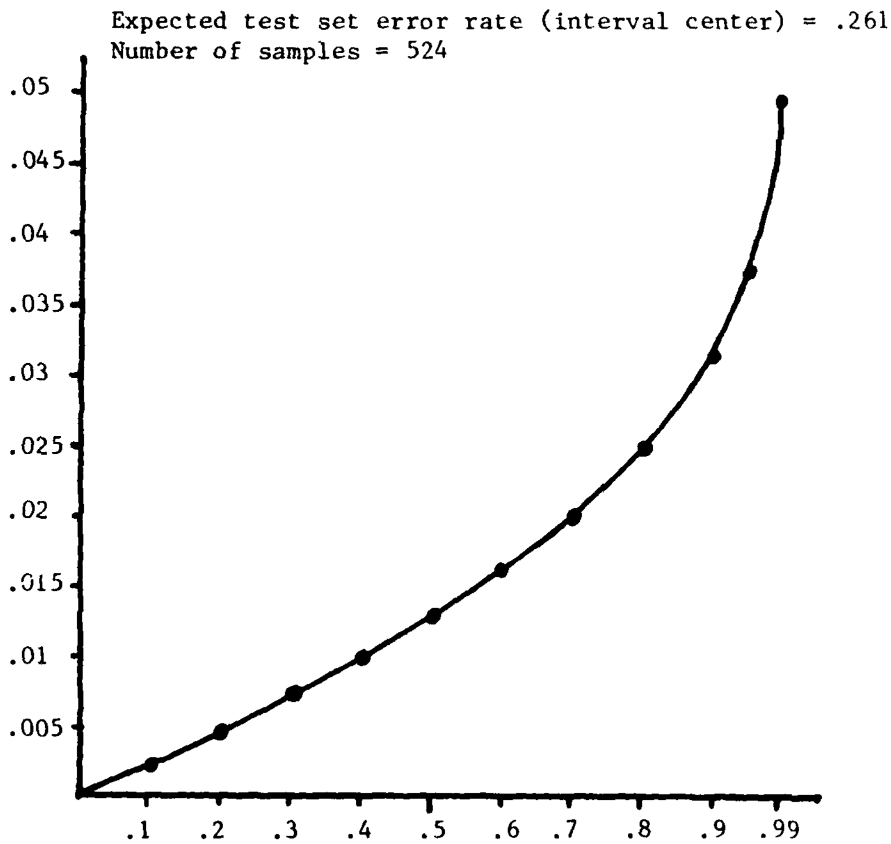

Fig. 6 Confidence Interval Graph
(13 Dimensions Composite)

CONCLUSIONS

This report has mentioned only a few of the discriminant analysis results achieved with this broach data set. Appendixes A and B contain lists of discriminant functions obtained from various analyses and the classification results achieved on complementary test sets. In spite of this mass of statistics, the sensitivity study conducted in this project was by no means exhaustive; it would not be practical to consider all subsets of the fourteen measurements. Furthermore, the method of training and testing is not optimal in the sense that, in general, only one part of the data set was used for generating the discriminants and the remaining portion was used for testing. A more elaborate scheme for computing the discriminant from all but one point in the data set, testing on the one holdout point and repeating until each point is used once as a holdout would provide statistically more valid discrimination results but require too much time to perform. The results obtained in the present analysis, when properly considered within the test conditions used and with the associated confidence intervals, do support the following conclusion: Broach is separable from no-broach with low error and moderate false alarm rates. Draft, as might be expected, is a significant measurement parameter, and heading, when used in a multiple discriminant context, offers improved separability. No measurement parameter other than draft exhibited any clearly greater effect on results than any other parameter. However, this analysis shows that sets of other parameters (which are more easily measured and controlled than draft) can recognize broach nearly as well as the draft measurement. Finally, all results and conclusions, strictly speaking, apply only to the operating conditions during the given tests. Among these conditions, low sea states and unevenly distributed speed data are the most notable.

REFERENCES

1. Garner, J., "Report on Progress of Analysis of Broaching Data," presented to Project Manager, Surface Effect Ships Program Office (PMS 304-32) (20 September 1976).

2. Sammon, J. W., "The On-Line Pattern Analysis and Recognition System - OLPARS," Rome Air Development Center Technical Report TR-68-263.

APPENDIX A

DISCRIMINANT FUNCTIONS

The following pages contain a computer generated list of the 150 discriminant functions (hyperplanes) considered in the broaching analysis. The planes are considered to be of the form

$$a_1x_1 + a_2x_2 + \ldots + a_{20}x_{20} + a_{21} = 0$$

where the a_i's are the coefficients of the function. In the listing that follows, the function number is given and the twenty-one coefficients describing that function are listed below the function number. The first twenty coefficients correspond to the twenty measurement parameters of the initial space. If a measurement is not being considered its corresponding coefficient value is zero. For example, function number thirty may be considered a function in 14-dimensional space operating on measurements 1-7, 10, 11, 13, 14,15, 19, and 20.

1.	2.	3.	4.	5.	6.	7.
-0.0165	-0.0166	-0.0164	-0.0164	-0.0158	-0.0159	0.0048
0.0400	0.0391	0.0404	0.0405	0.0163	0.0162	-0.0494
-0.6170	-0.0601	-0.0625	-0.0626	0.0112	0.0115	-0.0270
-0.0518	-0.0517	-0.0517	-0.0517	-0.0499	-0.0499	-0.0520
0.0112	0.0109	0.0114	0.0114	-0.0125	-0.0126	0.0405
-0.0019	-0.0018	-0.0019	-0.0019	0.0085	0.0086	0.0076
-0.0033	-0.0028	-0.0037	-0.0037	-0.0121	-0.0120	0.0076
0.6986	0.6963	0.6974	0.6970	0.6925	0.6930	0.5047
-0.6753	-0.6735	-0.6737	-0.6734	-0.6910	-0.6913	-0.4479
0.0130	0.0130	0.0130	0.0129	0.0149	0.0149	0.0810
0.0226	0.0227	0.0224	0.0224	0.0223	0.0223	0.0582
0.0057	-0.0790	0.0625	0.0698	0.0418	0.0251	-0.0320
-0.0681	-0.0682	-0.0677	-0.0677	-0.0744	-0.0745	-0.1244
-0.0025	-0.0027	-0.0024	-0.0023	-0.0188	-0.0188	0.0045
-0.0008	-0.0009	-0.0007	-0.0007	-0.0130	-0.0130	0.0108
0.0089	0.0083	0.0093	0.0093	0.0368	0.0368	-0.1349
0.0159	0.0164	0.0154	0.0154	0.0730	0.0733	0.6893
-0.1806	-0.1804	-0.1801	-0.1800	-0.1454	-0.1456	-0.1286
-0.0134	-0.0135	-0.0133	-0.0133	-0.0053	-0.0053	-0.0072
0.0948	0.0935	0.0952	0.0953	0.0551	0.0548	0.0203
0.3701	0.3712	0.4032	0.4508	-1.4899	-1.5097	-8.3348

8.	9.	10.	11.	12.	13.	14.
0.0048	0.0078	0.0783	0.0783	0.0261	-0.0416	-0.0124
-0.0496	0.1134	-0.0498	-0.0505	0.0192	0.0479	0.0739
-0.0267	-0.1168	-0.0128	-0.0109	-0.0634	0.0824	-0.0573
-0.0519	-0.0779	-0.0577	-0.0577	-0.0397	0.0312	-0.0150
0.0404	0.0563	-0.0099	-0.0103	-0.0002	0.0031	0.0025
0.0075	0.0185	0.0337	0.0337	0.0140	0.0271	0.0081
0.0076	0.0041	-0.0057	-0.0051	-0.0039	-0.0434	-0.0002
0.5043	0.7435	0.8693	0.8731	0.7090	0.8035	0.7145
-0.4477	-0.5215	0.3779	0.3791	-0.6503	0.3848	-0.6345
0.0809	0.0176	0.0240	0.0241	0.0097	0.0304	0.0093
0.0582	0.0353	0.0444	0.0448	0.0293	0.0334	0.0185
-0.0509	-0.0151	0.0927	-0.0296	-0.0977	0.0197	0.1933
-0.1243	-0.0322	-0.1026	-0.1030	-0.0175	-0.1510	-0.0816
0.0044	0.0005	0.0166	0.0163	0.0002	0.0067	-0.0071
0.0107	-0.0049	0.0192	0.0189	0.0040	0.0075	-0.0052
-0.1349	0.0504	-0.1033	-0.1038	0.0304	0.0753	0.0440
0.6888	-0.1426	0.0445	0.0443	-0.1532	0.3188	0.1461
-0.1285	-0.3144	-0.1268	-0.1280	-0.1377	-0.2421	-0.0869
-0.0072	-0.0271	-0.0085	-0.0086	-0.0343	0.0260	0.0142
0.0200	0.1175	0.1925	0.1913	0.1104	0.0021	0.0470
-8.3178	0.7374	2.2521	2.3218	1.8870	-5.6481	-4.3299

15.	16.	17.	18.	19.	20.	21.
0.0140	-0.0177	-0.0176	-0.0175	-0.0174	-0.0125	[illegible]
0.0829	0.0331	0.0323	0.0395	0.0413	0.0364	0.0365
-0.0181	0.0042	0.0056	-0.1105	-0.1154	-0.1227	-0.1228
-0.0252	-0.0447	-0.0446	-0.0368	-0.0367	-0.0414	-0.0413
-0.0049	-0.0051	-0.0054	0.0223	0.0231	0.0327	[illegible]
0.0165	0.0112	0.0112	-0.0118	-0.0119	-0.0008	-0.0008
-0.0237	0.0095	0.0097	-0.0104	-0.0117	-0.0162	-0.0162
0.8564	0.7093	0.7060	0.6792	0.6830	0.7351	0.7344
-0.4465	-0.6793	-0.6753	-0.6460	-0.6510	-0.6106	-0.6100
0.0136	0.0244	0.0242	0.0471	0.0472	0.0	0.0
0.0170	0.0257	0.0258	0.0251	0.0250	0.0179	[illegible]
-0.0733	-0.0198	-0.1042	-0.1300	0.0479	0.0801	[illegible]
-0.0986	-0.0814	-0.0810	-0.0521	-0.0523	-0.0502	[illegible]
-0.0050	-0.0086	-0.0087	0.0169	0.0176	-0.0011	[illegible]
-0.0001	-0.0044	-0.0044	0.0166	0.0170	-0.0030	[illegible]
0.1140	0.0305	0.0300	0.0208	0.0226	0.0055	[illegible]
0.1139	0.0681	0.0674	0.0452	0.0480	-0.0440	[illegible]
[illegible]	-0.1125	-0.1128	-0.2807	-0.2829	-0.2359	[illegible]
[illegible]	0.0022	0.0020	-0.0039	-0.0037	0.0039	[illegible]
[illegible]	0.0717	0.0700	0.0298	0.0313	0.0189	0.0189
-0.8289	-2.5576	-2.5108	-0.0459	-0.0567	2.4885	2.5451

22.	23.	24.	25.	26.	27.	28.
-0.0127	-0.9859	-0.0120	-0.0119	-0.0166	-0.0025	-0.0268
0.0355	0.0312	-0.0180	-0.0187	-0.0387	0.0394	0.1829
-0.1205	0.0047	0.0019	0.0034	-0.0059	-0.0181	[illegible]
-0.0418	0.0245	-0.0310	-0.0314	-0.0233	-0.0350	-0.0828
0.0324	-0.0003	-0.0044	-0.0044	0.0271	-0.0035	0.0168
-0.0008	-0.0288	-0.0329	-0.0320	-0.0101	-0.0017	[illegible]
-0.0154	-0.1092	0.0073	0.0077	-0.0047	-0.0034	[illegible]
0.7379	0.0378	0.5476	0.5365	0.4966	0.6086	0.5064
-0.6119	0.0409	-0.5702	-0.5585	-0.7154	-0.6253	-0.6347
0.0	0.0	0.0058	0.0057	0.0151	0.0041	0.0209
0.0180	-0.0837	0.0072	0.0072	0.0134	0.0023	0.0375
-0.0313	0.0001	-0.0670	-0.2101	-0.4040	0.0489	-0.1140
-0.0504	0.0162	-0.0246	-0.0248	-0.0423	-0.0046	-0.1998
-0.0015	-0.0057	0.0057	0.0055	0.0190	0.0145	-0.0154
-0.0033	-0.0014	0.0108	0.0105	0.0236	0.0203	-0.0116
0.0044	0.0552	-0.0382	-0.0393	-0.0829	0.0154	[illegible]
-0.0459	-0.0060	-0.6047	-0.5926	-0.2553	-0.4819	[illegible]
-0.2362	-0.0004	0.0	0.0	0.0	0.0	0.0
0.0038	0.0154	0.0	0.0	0.0	0.0	0.0
0.0180	-0.0011	0.0	0.0	0.0	0.0	0.0
2.4706	27.3927	14.9843	14.7677	10.6534	10.3180	[illegible]

29.	30.	31.	32.	33.	34.	35.
-0.0[illegible]10	-0.1290	-0.1682	-0.1647	-0.1519	-0.1465	-0.1617
0.1922	-0.1667	0.1325	-0.0764	-0.0041	0.0005	-0.3627
-0.0630	-0.2056	-0.3481	-0.3349	-0.4551	-0.5188	0.0500
-0.1311	-0.1201	-0.1554	-0.1087	-0.0663	-0.0645	0.0716
-0.0075	-0.0439	0.0051	-0.0202	-0.1437	-0.1447	-0.0322
0.0731	0.0318	0.1259	0.0841	-0.0674	-0.0662	-0.1947
0.0338	0.0298	0.1680	0.1055	0.2551	0.2454	0.0764
0.6130	0.0	0.0	0.0	0.0	0.0	0.0
-0.6814	0.0	0.0	0.0	0.0	0.0	0.0
0.0189	0.3640	0.4003	0.4117	0.4107	0.3990	0.5472
[illegible].0143	0.2401	0.2547	0.2441	0.2793	0.2700	0.2497
[illegible].0147	0.0	0.0	0.0	0.0	0.0	0.0
[illegible].1814	-0.7758	-0.6070	-0.7001	-0.6176	-0.5909	-0.5873
[illegible].0295	0.0695	0.0614	0.1118	0.1050	0.1027	0.1921
[illegible].0226	0.1047	0.0848	0.1368	0.1218	0.1205	0.2152
0.0[illegible]62	0.0	0.0	0.0	0.0	0.0	0.0
0.[illegible]298	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.1027	0.2041	0.1660	0.1070	0.1146	0.0
0.0	-0.2770	-0.3444	-0.2155	0.0984	-0.0126	0.0
-1.[illegible]924	6.5915	-3.4782	1.6117	-10.1442	-8.8143	4.5692

36.	37.	38.	39.	40.	41.	42.
-0.1584	-0.1821	-0.1812	-0.1641	-0.1529	-0.1900	-0.1864
-0.4143	-0.3671	-0.3144	-0.2503	-0.3205	-0.5821	-0.6016
-0.1326	-0.0889	0.0870	0.2799	0.1124	0.0263	-0.0800
0.0668	0.0976	0.0728	0.2098	0.0025	0.0281	0.0263
-0.0450	0.0874	0.0247	-0.0441	-0.0752	0.0390	0.0302
-0.1972	-0.1849	-0.1844	-0.2915	-0.2203	-0.0622	-0.0660
0.0813	0.0669	0.0604	-0.0092	-0.0015	-0.1215	-0.1127
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.5170	0.5337	0.5718	0.7503	0.6392	0.0	0.0
0.2498	0.3004	0.2860	0.1554	0.0	0.2472	0.2456
0.0	0.0	0.0	0.0	0.0	0.0	0.0
-0.5748	-0.6265	-0.6375	0.0	-0.5199	-0.7364	-0.7196
0.1792	-0.0288	0.0	0.2245	0.2324	-0.0093	-0.0128
0.[illegible]039	0.0	0.0453	0.2521	0.2724	-0.0009	-0.0028
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
4.4093	5.1128	5.9012	6.6724	10.0946	16.3291	15.2143

43.	44.	45.	46.	47.	48.	49.
-0.1607	-0.1734	-0.1624	-0.1611	-0.1016	-0.1621	-0.1876
-0.3703	-0.3538	-0.3749	-0.3685	-0.4387	-0.3532	0.2043
0.1319	0.1584	-0.0012	-0.0854	-0.7082	-0.0296	0.0
0.0743	0.0674	0.0732	0.0	0.0	0.0	[illegible]
-0.0413	-0.0500	0.0	-0.0512	-0.0798	-0.0474	-0.0436
-0.2098	0.0	-0.2020	-0.1972	-0.1494	-0.1964	-0.2682
0.0	0.0765	0.0796	0.0812	0.0746	0.0798	0.0522
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.5567	0.5520	0.5432	0.5315	0.2692	0.5406	[illegible]
0.2223	0.2459	0.2530	0.2419	0.1730	0.2417	[illegible]
0.0	0.0	0.0	0.0	0.0	0.0	0.0
-0.5717	-0.6044	-0.5874	-0.6022	-0.3745	-0.6066	[illegible]
0.1889	0.1833	0.1852	0.1836	0.0831	0.1876	0.1225
0.2159	0.2067	0.2052	0.2133	0.1087	0.2169	0.1694
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
9.6826	4.8340	4.3158	4.3045	0.0	4.5124	[illegible]

50.	51.	52.	53.	54.	55.	56.
-0.1655	0.0	-0.0345	-0.0345	-0.0297	-0.0203	-0.0204
0.0	-0.0370	0.0	0.0	0.0	0.0	0.0
0.0525	-0.5507	0.0	0.0	0.0	0.0	0.0
0.0306	0.0397	-0.0408	-0.0408	-0.0328	-0.0215	-0.0219
-0.0424	-0.0942	0.0	0.0	0.0	0.0	0.0
-0.2421	-0.4245	0.0	0.0	0.0	0.0	0.0
0.0975	-0.0958	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.5898	0.5896	0.6605	0.6590	0.6631
0.0	0.0	-0.6892	-0.6889	-0.6951	-0.7128	-0.7165
0.6205	0.6270	0.0573	0.0573	0.0415	0.0277	0.0277
0.2553	0.0082	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0619	0.0686	0.0484	0.1210	0.0547
-0.6049	-0.2627	-0.1528	-0.1528	-0.0879	-0.0592	-0.0592
0.1880	0.0907	0.0	0.0	0.0	0.0	0.0
0.2179	0.1586	0.0	0.0	0.0	0.0	0.0
0.0	0.0	-0.1291	-0.1291	-0.0854	0.0271	[illegible]
0.0	0.0	0.3282	0.3280	0.1787	0.1755	0.1772
0.0	0.0	-0.1363	-0.1361	-0.1657	-0.0779	-0.0797
0.0	0.0	0.0279	0.0279	0.0151	0.0182	0.0182
0.0	0.0	0.0	0.0	0.0	0.0	0.0
3.4337	10.1038	0.5242	0.7042	1.4576	-4.0626	-4.0801

57.	58.	59.	60.	61.	62.	63.
-0.0182	0.0	0.0	0.0	0.0	0.0	0.0
0.0	-0.0777	0.1225	0.1109	-0.0769	-0.1839	0.0465
0.0	-0.3703	0.1427	0.0731	-0.3366	0.2305	0.4015
-0.0344	0.0930	0.1812	0.1429	0.1282	0.1492	0.1606
0.0	-0.0348	0.0779	-0.0304	-0.0154	0.0200	0.0454
0.0	-0.2482	-0.5301	-0.5455	-0.2384	-0.5949	-0.2327
0.0	-0.2700	-0.1724	-0.1588	-0.2663	-0.7002	0.0
0.7280	0.0	0.0	0.0	0.0	0.0	0.0
-0.6680	0.0	0.0	0.0	0.0	0.0	0.0
0.0273	0.8369	0.7816	0.7944	0.8546	0.0	0.8482
0.0	-0.0849	-0.0065	-0.0178	0.0	-0.1674	-0.0045
0.0157	0.0	0.0	0.0	0.0	0.0	0.0
-0.0541	0.0	0.0	0.0	0.0	0.0	0.0
0.0	-0.0515	-0.0640	0.0	-0.0736	-0.1192	0.1018
0.0	0.0462	0.0	0.0825	0.0231	-0.0628	0.1579
-0.0294	0.0	0.0	0.0	0.0	0.0	0.0
0.0357	0.0	0.0	0.0	0.0	0.0	0.0
-0.1272	0.0	0.0	0.0	0.0	0.0	0.0
0.0034	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.4636	20.7237	13.5092	12.7515	20.0274	45.5703	3.4988

64.	65.	66.	67.	68.	69.	70.
0.0	0.0	0.0	0.0	0.0	0.0	0.0
-0.0317	-0.0432	-0.0636	-0.0527	0.0	-0.0253	0.0485
-0.1920	-0.4731	0.4346	0.0	-0.1966	-0.1175	-0.1291
0.1281	0.0976	0.0	0.1158	0.0955	0.1334	0.1809
-0.2179	0.0	0.0005	0.0057	-0.0265	-0.2153	-0.0667
0.0	-0.4171	-0.2605	-0.1882	-0.2649	0.0	0.0
-0.1608	-0.1641	-0.2482	-0.3169	-0.2774	-0.1623	-0.2191
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.8763	0.7368	0.7999	0.9122	0.8895	0.8847	0.9393
-0.0847	-0.0425	-0.1001	-0.1034	-0.0892	-0.0856	-0.0678
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.1762	0.0581	0.0734	-0.0583	-0.0351	0.1856	-0.0942
0.2575	0.1260	0.1498	0.0411	0.0635	0.2656	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
13.8693	13.1965	19.5355	23.9648	20.8892	14.1899	16.8675

71.	72.	73.	74.	75.	76.	77.
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0071	-0.0379	-0.2529	0.1064	-0.0183	0.0374	0.0981
-0.1702	-0.3080	-0.1396	-0.0697	0.1080	-0.0581	0.0
0.1382	0.1528	0.1286	0.1360	0.1705	0.0	0.1253
-0.1776	-0.2106	-0.1335	-0.1752	0.0	-0.2285	0.0102
0.0	0.0	0.0	0.0	0.0	0.0	0.0
-0.2034	-0.1396	-0.8639	0.0	-0.1635	-0.1669	-0.2602
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.9277	0.8600	0.0	0.9021	0.9124	0.8884	0.9432
-0.0821	0.0	-0.2646	-0.0353	-0.0810	-0.1129	-0.0956
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.1523	-0.2215	0.2075	0.1867	0.1894	[illegible]
0.1674	0.2317	-0.1298	0.2766	0.2415	0.2779	[illegible]
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
16.3625	12.3812	54.1391	3.3063	14.1023	14.1844	19.4691

78.	79.	80.	81.	82.	83.	84.
0.0	-0.1345	-0.1230	-0.1066	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
-0.0303	0.0	0.0	0.0	-0.3593	-0.4020	-0.1181
0.1348	0.0	0.0	0.0	0.1402	0.2228	0.2121
-0.2112	0.0	0.0	0.0	-0.2109	-0.0503	-0.0602
0.0	0.0	0.0	0.0	0.0	0.0	0.0
-0.1618	0.0	0.0	0.0	-0.1349	-0.2100	-0.2081
0.0	0.2164	0.4069	0.0436	0.0	0.0	0.0
0.0	-0.2917	0.4084	0.2360	0.0	0.0	0.0
0.8896	0.0	0.0	0.0	0.8485	0.9455	0.9407
-0.0861	0.2067	0.2643	0.2724	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	-0.6320	-0.6714	-0.8526	0.0	0.0	0.0
0.1976	0.0	0.0	0.0	0.1408	-0.0891	0.0
0.2711	0.0	0.0	0.0	0.2209	0.0	-0.0908
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	-0.5586	0.0643	0.2520	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.3093	0.3575	0.2578	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
14.0616	18.1726	3.5156	1.1364	11.9378	15.8123	[illegible]

85.	86.	87.	88.	89.	90.	91.
0.0	0.0	0.0	0.0	0.0	0.0	-0.1938
0.0	0.0	0.0	0.0	0.0	0.0	0.0
-0.1107	-0.1644	-0.2830	-0.3047	-0.2380	0.0	0.0
0.1774	0.1582	0.1510	0.1703	0.0	0.1540	0.0
-0.1643	-0.1711	-0.4245	0.0	-0.2193	0.0814	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
-0.1890	0.0	0.0	-0.1389	-0.1489	-0.2845	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.8999	0.7432	0.8978	0.8889	0.9406	0.4455
0.0	0.0	0.0	0.0	0.0	0.0	0.3075
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	-0.7044
0.9396	0.1959	0.2472	0.1296	0.1528	-0.0555	0.0
0.1032	0.2655	0.3216	0.1896	0.2442	0.0298	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0589
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.4121
0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.2343	3.2457	3.0282	12.3343	12.9700	20.5118	5.3320

92.	93.	94.	95.	96.	97.	98.
-0.1942	-0.1768	-0.1295	-0.2027	0.0	0.0	-0.3600
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.1005	0.0071	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	-0.3377	-0.4525	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.4463	0.4188	0.3402	0.4567	0.9304	0.8155	0.9170
0.3099	0.2693	0.2676	0.2944	0.0	0.0	0.1466
0.0	0.0	0.0	0.0	0.0	0.0	0.0
-0.7048	-0.7968	-0.8643	-0.7240	0.0	0.0	0.0
0.0	0.0	0.0	0.0	-0.1009	-0.3132	0.0
0.0	0.0	0.0	0.0	0.0048	-0.1790	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
-0.0494	0.0230	0.0813	-0.0170	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.4097	0.2924	0.2056	0.3730	0.0	0.0	0.0900
0.0	0.0	0.0	0.0	0.0	0.0	0.0
8.7202	6.9617	5.5622	7.4196	23.7924	30.3758	6.7443

99.	100.	101.	102.	103.	104.	105.
-0.2655	-0.2659	-0.2712	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0071	0.0139	0.2827	0.1461
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	-0.3905	-0.3835	-0.8522	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.9364	0.9380	0.8831	0.9141	0.9178	0.0	0.9731
0.2116	0.2117	0.3757	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	-0.1089	0.0	-0.3466	[illegible]
0.0	0.0	0.0	0.0	0.1021	[illegible]	[illegible]
0.0	0.0	0.0	0.0	0.0	0.0	[illegible]
-0.0890	-0.0686	-0.0735	0.0	0.0	0.0	[illegible]
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
[illegible]	7.3603	8.5487	27.5807	28.1868	52.4139	[illegible]

106.	107.	108.	109.	110.	111.	[illegible]
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
[illegible]	-0.2303	-0.2362	-0.3025	-0.9981	0.0	[illegible]
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	[illegible]
[illegible]	0.9591	0.9665	0.9478	0.0	[illegible]	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	[illegible]
[illegible]	0.0643	-0.1006	0.0	-0.0204	0.1226	0.0
[illegible]	0.1515	0.0	0.1008	0.0584	[illegible]	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	[illegible]
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
[illegible]	18.3521	18.2085	23.1132	63.8818	4.2251	[illegible]

113.	114.	115.	116.	117.	118.	119.
0.0	0.0	0.0	0.0	0.0	0.0	-0.2523
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
-0.5114	0.7709	0.0	-0.9853	0.0	-0.8111	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.9656
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
-0.8590	0.6369	-0.9998	0.0	-0.9118	-0.5849	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
-0.0247	0.0	-0.0174	-0.1706	0.4105	0.0	-0.0635
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
39.1669	-54.1886	6.8344	66.4484	-3.0188	56.1251	8.4009

120.	121.	122.	123.	124.	125.	126.
-0.2498	0.2132	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	-0.1311
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.4552	-0.8129	0.8110	0.9782	0.9999	0.9948	0.9914
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.1007	-0.0152	0.0	0.0
0.0	0.0	0.0	0.1815	0.0	0.1014	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
-0.1528	0.5420	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.3326	0.0	0.0	0.0	0.0
0.0	0.0	0.4814	0.0	0.0	0.0	0.0
10.3585	-22.1554	0.6280	4.3779	3.2314	3.6336	11.2739

127.	128.	129.	130.	131.	132.	133.
0.0	0.0	-0.2862	-0.0274	-0.0986	-0.0471	-0.0306
0.0	0.0	0.0	0.4952	0.1031	0.3989	0.4848
0.0	0.0481	0.0	-0.0886	-0.5116	-0.3871	-0.1344
0.0	0.0	0.0	0.6684	0.2174	0.5537	0.6566
0.2039	0.0	0.0	0.2017	0.0836	0.1830	0.2005
0.0	0.0	0.0	-0.3328	-0.7115	-0.4182	-0.3484
0.0	0.0	0.0	-0.0946	0.0470	-0.0885	-0.0945
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.9790	0.9988	0.9582	0.0035	0.0517	-0.0066	0.0020
0.0	0.0	0.0	-0.1573	0.0167	-0.1082	-0.1512
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	-0.1012	-0.3089	-0.1763	-0.1134
0.0	0.0	0.0	0.2504	0.1878	0.2736	0.2560
0.0	0.0	0.0	0.2036	0.1471	0.2197	0.2077
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
3.0664	2.4163	7.0082	9.6118	2.5638	10.1959	9.7629

134.	135.	136.	137.	138.	139.	140.
-0.1677	-0.2245	-0.1942	-0.2099	-0.0466	-0.0694	-0.0605
-0.1365	0.1317	-0.1241	-0.0318	-0.0267	-0.1606	0.1090
-0.3579	-0.1963	-0.3303	0.5033	0.1852	-0.4779	-0.6210
-0.4427	-0.2678	-0.4328	-0.1737	-0.0455	-0.2006	-0.1422
0.4007	0.2704	0.4051	0.3024	0.1548	0.1085	-0.0648
-0.0554	-0.1962	-0.1400	-0.2050	-0.5254	-0.3141	-0.2106
-0.0704	0.0070	-0.0839	-0.0184	-0.2523	0.0055	-0.2117
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.1465	0.4393	0.2066	0.4379	0.2223	0.0270	0.2432
0.2652	0.3721	0.2973	0.3289	0.2741	0.1043	0.3063
0.0	0.0	0.0	0.0	0.0	0.0	0.0
-0.5395	-0.6006	-0.5605	-0.4577	-0.6156	-0.6114	-0.5009
0.1366	0.1269	0.1146	0.1616	-0.1374	-0.1501	-0.2080
0.0645	0.0169	0.0369	0.0452	-0.1439	-0.1486	-0.1843
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
-0.2344	-0.0438	0.0	0.0	0.2325	0.4003	0.0
12.9948	9.7393	14.2176	11.3815	20.6371	3.9007	16.80[illegible]

141.	142.	143.	144.	145.	146.	147.
-0.0843	0.0	0.0	0.0641	0.0258	0.0873	0.0609
-0.2417	0.0	0.0	0.2010	0.0890	0.4485	0.6259
-0.0455	0.0	0.0	0.3358	-0.4829	-0.1363	-0.0083
-0.0968	0.0	0.0	0.3272	-0.5225	0.2225	-0.0526
0.2148	0.0	0.0	-0.3127	-0.2730	-0.4020	-0.5335
-0.5169	0.0	0.0	0.4328	0.0160	0.2871	0.2054
-0.0398	0.0	0.0	-0.6130	-0.4162	-0.6382	-0.4543
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0606	1.0000	1.0000	-0.0446	-0.0801	0.0051	-0.0870
0.1259	0.0	0.0	-0.1318	0.1060	-0.0668	0.0581
0.0	0.0	0.0	0.0	0.0	0.0	0.0
-0.2517	0.0	0.0	-0.1446	-0.3135	-0.2486	-0.1452
-0.1083	-0.0033	-0.0076	0.0434	-0.2091	-0.0740	-0.1667
-0.1086	0.0	0.0	0.0563	-0.0836	-0.0076	-0.0935
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	-0.1718	0.2656	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0
9.2770	1.0333	3.7215	40.6538	27.2686	41.6754	27.9933

148.	149.	150.
-0.2391	-0.2377	0.0
-0.1258	-0.2639	0.0
-0.1918	-0.1225	0.0
-0.1406	-0.1045	0.0
0.1676	0.1547	0.0
-0.0112	-0.0485	0.0
0.0663	0.1015	0.0
0.0	0.0	0.0
0.0	0.0	0.0
0.2275	0.2456	1.0000
0.2890	0.3088	0.0
0.0	0.0	0.0
-0.7841	-0.7844	0.0
-0.1356	-0.1519	0.0047
-0.1330	-0.1316	0.0
0.0	0.0	0.0
0.0	0.0	0.0
0.0	0.0	0.0
[illegible]	0.0	0.0
0.0	0.0	0.0
4.6483	3.3183	3.1222

APPENDIX B
CLASSIFICATION RESULTS FOR DISCRIMINANT FUNCTIONS

Discriminant functions were typically generated by OLPARS analysis of data composing only a subset of the whole data set, thereby allowing a complementary set of data with which to statistically test the accuracy of the discriminants. The following tables refer to these data sets by name. The composition of these sets is described in a separate table at the end of this appendix.

The numbers listed for false alarm and error rates are in terms of percentages. For example, the Zone 0 false alarm rate for plane number one is given as the number, 5. This means that 5% of Zone 0 was classed as broach for a false alarm rate of 5% or .05.

PLANE NO.	ID	ANALYSIS SET	TEST SET	# DIM	MEASUREMENTS USED	FALSE ALARM RATES ZONE 0	FALSE ALARM RATES ZONE 1	ERROR RATES ZONE 2	ERROR RATES ZONE 3
1	11.18.1	DATASET1	DATASET2	20	1-20	5	19	60	45
2	11.18.2	DATASET1	DATASET2	20	1-20	12	49	13	5.5
3	11.18.3	DATASET1	DATASET2	20	1-20	10.5	49	13	6.8
4	11.18.4	DATASET1	DATASET2	20	1-20	5.3	32	24.6	9.6
5	11.18.5	DATASET1	DATASET2	20	1-20	7.9	45	19.6	5.6
6	11.18.6	DATASET1	DATASET2	20	1-20	11.8	51	18.8	9.6
7	12.12.1	SPEED3	SPEED3	20	1-20	26	84	5	1
8	12.12.2	SPEED3	SPEED3	20	1-20	22	57	13	2
9	12.12.3	SPEED3	SPEED3	20	1-20	7	59	15	0
10	12.12.4	SPEED2	SPEED2	20	1-20	31	87	2	0
11	12.12.5	SPEED2	SPEED2	20	1-20	22	67	2	0
12	12.12.6	SPEED2	SPEED2	20	1-20	24	56	5	3
13	12.12.7	SPEED1	SPEED1	20	1-20	48	92	6	3
14	12.12.8	SPEED1	SPEED1	20	1-20	46	92	6	3
15	12.12.9	SPEED1	SPEED1	20	1-20	18	27	14	6
16	11.17.1	ZONES03	Whole Data Set	20	1-20	24	67	8	4
17	11.17.2	ZONES03	Whole Data Set	20	1-20	19	64	12	3
18	3.9.1	ONEPAGE	TEST1PAGE	20	1-20	20	56	14.5	6.1
19	3.9.2	ONEPAGE	TEST1PAGE	20	1-20	15	45	19.6	11.3
20	3.9.3	ONEPAGE	TEST1PAGE	19	1-9, 11-20	29	56	8.8	11.3
21	3.9.4	ONEPAGE	TEST1PAGE	19	1-9, 11-20	12	36	25.7	20.9
22	3.9.5	ONEPAGE	TEST1PAGE	19	1-9, 11-20	40	72	4.7	5.2
23	3.9.6	ONEPAGE	TEST1PAGE	19	1-9, 11-20	22	40	46	43
24	12.2.1	CALM	CALM	17	1-17	12	35	2	0
25	12.2.2	CALM	CALM	17	1-17	2	17	16	0
26	12.2.3	CALM	CALM	17	1-17	20	58	0	3
27	12.2.4	CALM	CALM	17	1-17	2	74	32	0
28	12.20.1	P1STATES12	STATES12-P1STATES12	17	1-17	40	83	7	4
29	12.20.2	P1STATES12	STATES12 P1STATES12	17	1-17	23	60	23	11
30	12.14.6	DATASET2	DATASET1	14	1-7, 10, 11, 13, 14, 15, 19, 20	49	92	5.8	2.7

PLANE NO.	ID	ANALYSIS SET	TEST SET	# DIM	MEASUREMENTS USED	FALSE ALARM RATES ZONE 0	ZONE 1	ERROR RATES ZONE 2	ZONE 3
31	12.14.7	DATASET2	DATASET1	14	1-7, 10, 11, 13, 14, 15, 19, 20	58	91	3.6	2.7
32	12.14.8	DATASET2	DATASET1	14	1-7, 10, 11, 13, 14, 15, 19, 20	55	92	5.1	2.7
33	12.14.9	DATASET2	DATASET1	14	1-7, 10, 11, 13, 14, 15, 19, 20	62	92	2.2	1.4
34	12.14.10	DATASET2	DATASET1	14	1-7, 10, 11, 13, 14, 15, 19, 20	50	78	8.7	1.4
35	1.24.1.1	ONEPAGE	TEST1PAGE	12	1-7, 10, 11, 13, 14, 15	36	79	9.4	6.1
36	1.24.1.2	ONEPAGE	TEST1PAGE	12	1-7, 10, 11, 13, 14, 15	27	60	17.3	12.2
37	1.24.2	ONEPAGE	TEST1PAGE	11	1-7, 10, 11, 13, 14	34	63	14.5	7.0
38	1.24.3	ONEPAGE	TEST1PAGE	11	1-7, 10, 11, 13, 15	33	63	14.0	7.0
39	1.24.4	ONEPAGE	TEST1PAGE	11	1-7, 10, 11, 14, 15	44	72	8.9	2.6
40	1.24.5	ONEPAGE	TEST1PAGE	11	1-7, 10, 13, 14, 15	30	67	10.8	7.8
41	1.24.6.1	ONEPAGE	TEST1PAGE	11	1-7, 11, 13, 14, 15	54	88	8.4	13.0
42	1.24.6.2	ONEPAGE	TEST1PAGE	11	1-7, 11, 13, 14, 15	60	90	4.7	7.8
43	1.24.7	ONEPAGE	TEST1PAGE	11	1-6, 10, 11, 13, 14, 15	37	76	9.4	8.7
44	1.24.8	ONEPAGE	TEST1PAGE	11	1-5, 7, 10, 11, 13, 14, 15	37	79	8.4	6.1
45	1.24.9	ONEPAGE	TEST1PAGE	11	1-4, 6, 7, 10, 11, 13, 14, 15	37	79	9.4	6.1
46	1.24.10.1	ONEPAGE	TEST1PAGE	11	1-3, 5-7, 10, 11, 13, 14, 15	36	72	9.8	7.0
47	1.24.10.2	ONEPAGE	TEST1PAGE	11	1-3, 5-7, 10, 11, 13, 14, 15	59	90	2.8	3.5

PLANE NO.	ID	ANALYSIS SET	TEST SET	# DIM	MEASUREMENTS USED	FALSE ALARM RATES ZONE 0	ZONE 1	ERROR RATES ZONE 2	ZONE 3
48	1.24.10.3	ONEPAGE	TEST1PAGE	11	1-3, 5-7, 10, 11, 13, 14, 15	36	72	9.8	7.8
49	1.24.11	ONEPAGE	TEST1PAGE	11	1, 2, 4-7, 10, 11, 13, 14, 15	42	78	7.5	4.4
50	1.24.12	ONEPAGE	TEST1PAGE	11	1, 3-7, 10, 11 13, 14, 15	37	74	12.2	6.1
51	1.24.13	ONEPAGE	TEST1PAGE	11	2-7, 10, 11, 13 14, 15	44	83	11.2	2.6
52	12.7.1	DATASET2	DATASET1	11	1, 4, 8, 9, 10, 12, 13, 16, 17, 18, 19	62	96	1.4	0
53	12.7.2	DATASET2	DATASET1	11	1, 4, 8, 9, 10, 12, 13, 16, 17, 18, 19	45	85	10.1	1.4
54	12.7.3	DATASET2	DATASET1	11	1, 4, 8, 9, 10, 12, 13, 16, 17, 18, 19	38	74	9.4	2.7
55	12.7.4	DATASET2	DATASET1	11	1, 4, 8, 9, 10, 12, 13, 16, 17, 18, 19	43	78	6.5	2.7
56	12.7.5	DATASET2	DATASET1	11	1, 4, 8, 9, 10, 12, 13, 16, 17, 18, 19	34	73	8.7	2.7
57	12.7.6	DATASET2	DATASET1	11	1, 4, 8, 9, 10, 12, 13, 16, 17, 18, 19	42	79	4.4	1.4
58	2.17.1	ONEPAGE	TEST1PAGE	10	2-7, 10, 11,14, 15	35	66	15.9	5.2
59	2.17.2	ONEPAGE	TEST1PAGE	9	2-7, 10, 11, 14	44	78	13.1	4.4
60	2.17.3	ONEPAGE	TEST1PAGE	9	2-7, 10, 11, 15	45	80	11.2	4.4
61	2.17.4	ONEPAGE	TEST1PAGE	9	2-7, 10, 14, 15	41	70	15.4	4.4
62	2.17.5	ONEPAGE	TEST1PAGE	9	2-7, 11, 14, 15	63	86	16.4	13.0

PLANE NO.	ID	ANALYSIS SET	TEST SET	# DIM	MEASUREMENTS USED	FALSE ALARM RATES ZONE 0	ZONE 1	ERROR RATES ZONE 2	ZONE 3
63	2.17.6	ONEPAGE	TEST1PAGE	9	2-6, 10, 11, 14 15	35	64	18.7	4.4
64	2.17.7	ONEPAGE	TEST1PAGE	9	2-5, 7, 10, 11 14, 15	44	76	11.2	1.7
65	2.17.8	ONEPAGE	TEST1PAGE	9	2-4, 6, 7, 10, 11, 14, 15	43	76	11.7	3.5
66	2.17.9	ONEPAGE	TEST1PAGE	9	2, 3, 5-7, 10 11, 14, 15	41	73	13.1	4.4
67	2.17.10	ONEPAGE	TEST1PAGE	9	2, 4-7, 10, 11, 14, 15	40	69	15.0	4.4
68	2.17.11	ONEPAGE	TEST1PAGE	9	3-7, 10, 11, 14 15	44	77	12.2	2.6
69	2.24.1	ONEPAGE	TEST1PAGE	9	2-5, 7, 10, 11, 14, 15	42	72	11.7	1.7
70	2.24.2	ONEPAGE	TEST1PAGE	8	2-5, 7, 10, 11, 14	44	77	12.6	2.6
71	2.24.3	ONEPAGE	TEST1PAGE	8	2-5, 7, 10, 11, 15	40	71	13.6	2.6
72	2.24.4	ONEPAGE	TEST1PAGE	8	2-5, 7, 10, 14, 15	40	71	14.0	1.7
73	2.24.5	ONEPAGE	TEST1PAGE	8	2-5, 7, 11, 14, 15	80	92	10.3	8.7
74	2.24.6	ONEPAGE	TEST1PAGE	8	2-5, 10, 11, 14, 15	44	75	13.1	1.7
75	2.24.7	ONEPAGE	TEST1PAGE	8	2-4, 7, 10, 11, 14, 15	48	81	9.4	1.7
76	2.24.8	ONEPAGE	TEST1PAGE	8	2, 3, 5, 7, 10, 11, 14, 15	45	76	9.8	1.7
77	2.24.9	ONEPAGE	TEST1PAGE	8	2, 4, 5, 7, 10, 11, 14, 15	49	81	7.9	1.7
78	2.24.10	ONEPAGE	TEST1PAGE	8	3-5, 7, 10, 11, 14, 15	43	76	11.2	1.7

PLANE NO.	ID	ANALYSIS SET	TEST SET	# DIM	MEASUREMENTS USED	FALSE ALARM RATES ZONE 0	FALSE ALARM RATES ZONE 1	ERROR RATES ZONE 2	ERROR RATES ZONE 3
79	11.30.1	ONEPAGE	TEST1PAGE	7	1, 8, 9, 11, 13, 17, 19	32	66	21.7	14.9
80	11.30.2	ONEPAGE	TEST1PAGE	7	1, 8, 9, 11, 13, 17, 19	43	73	15.2	13.5
81	11.30.3	ONEPAGE	TEST1PAGE	7	1, 8, 9, 11, 13, 17, 19	42	78	16.7	13.5
82	2.27.1	ONEPAGE	TEST1PAGE	7	3, 4, 5, 7, 10, 14, 15	41	71	13.6	1.7
83	2.27.2	ONEPAGE	TEST1PAGE	6	3-5, 7, 10, 14	45	79	11.7	1.7
84	2.27.3	ONEPAGE	TEST1PAGE	6	3-5, 7, 10, 15	50	80	12.6	4.4
85	2.27.4	ONEPAGE	TEST1PAGE	6	3-5, 7, 14, 15	57	64	39.7	33.0
86	2.27.5.1	ONEPAGE	TEST1PAGE	6	3-5, 10, 14, 15	44	74	13.5	1.7
87	2.27.5.2	ONEPAGE	TEST1PAGE	6	3-5, 10, 14, 15	42	72	13.1	3.5
88	2.27.6	ONEPAGE	TEST1PAGE	6	3, 4, 7, 10, 14, 15	43	75	13.1	1.7
89	2.27.7	ONEPAGE	TEST1PAGE	6	3, 5, 7, 10, 14, 15	42	72	12.6	1.7
90	2.27.8	ONEPAGE	TEST1PAGE	6	4, 5, 7, 10, 14, 15	49	86	7.9	1.7
91	12.14.1	DATASET2	DATASET1	6	1, 10, 11, 13, 17, 19	67	97	3.6	0
92	12.14.2	DATASET2	DATASET1	6	1, 10, 11, 13, 17, 19	51	86	5.1	4.1
93	12.14.3	DATASET2	DATASET1	6	1, 10, 11, 13, 17, 19	67	96	3.6	0
94	12.14.4	DATASET2	DATASET1	6	1, 10, 11, 13, 17, 19	63	97	2.9	0
95	12.14.5	DATASET2	DATASET1	6	1, 10, 11, 13 17, 19	67	97	2.9	0
96	2.24.1.1	ONEPAGE	TEST1PAGE	5	4, 7, 10, 14, 15	48	85	7.0	1.7
97	2.24.1.2	ONEPAGE	TEST1PAGE	5	4, 7, 10, 14 15	47	82	10.1	2.6

PLANE NO.	ID	ANALYSIS SET	TEST SET	# DIM	MEASUREMENTS USED	FALSE ALARM RATES ZONE 0	FALSE ALARM RATES ZONE 1	ERROR RATES ZONE 2	ERROR RATES ZONE 3
98	12.16.4	DATASET2	DATASET1	4	1, 10, 11, 19	62	88	3.6	2.7
99	12.16.1	DATASET2	DATASET1	4	1, 10, 11, 17	34	64	18.1	6.8
100	12.16.2	DATASET2	DATASET1	4	1, 10, 11, 17	61	88	2.9	1.4
101	12.16.3	DATASET2	DATASET1	4	1, 10, 11, 17	43	73	11.6	6.8
102	2.28.2	ONEPAGE	TEST1PAGE	4	4, 7, 10, 14	46	80	10.3	2.6
103	2.28.3	ONEPAGE	TEST1PAGE	4	4, 7, 10, 15	42	74	17.3	3.5
104	2.28.4	ONEPAGE	TEST1PAGE	4	4, 7, 14, 15	76	90	10.3	7.8
105	2.28.5	ONEPAGE	TEST1PAGE	4	4, 10, 14, 15	34	59	20.1	5.2
106	2.28.6	ONEPAGE	TEST1PAGE	4	7, 10, 14, 15	45	77	11.2	1.7
107	3.1.1	ONEPAGE	TEST1PAGE	4	7, 10, 14, 15	41	74	13.5	2.6
108	3.1.2	ONEPAGE	TEST1PAGE	3	7, 10, 14	41	72	13.5	4.4
109	3.1.3	ONEPAGE	TEST1PAGE	3	7, 10, 15	40	70	16.4	2.6
110	3.1.4	ONEPAGE	TEST1PAGE	3	7, 14, 15	68	86	15.4	12.2
111	3.1.5	ONEPAGE	TEST1PAGE	3	10, 14, 15	28	50	22.0	5.2
112	3.3.1	ONEPAGE	TEST1PAGE	3	7, 13, 17	63	91	7.9	8.7
113	3.3.2	ONEPAGE	TEST1PAGE	3	7, 13, 17	58	89	10.7	12.2
114	3.3.3	ONEPAGE	TEST1PAGE	2	7, 13	60	86	14.5	14.8
115	3.3.4	ONEPAGE	TEST1PAGE	2	13,17	48	79	21.0	13.0
116	3.3.5	ONEPAGE	TEST1PAGE	2	7, 17	71	88	13.1	8.7
117	3.3.6	ONEPAGE	TEST1PAGE	2	13, 17	46	79	22.9	15.6
118	3.3.7	ONEPAGE	TEST1PAGE	2	7, 13	63	88	12.6	12.2
119	12.28.1	DATASET2	DATASET1	3	1, 10, 17	49	76	6.6	2.7
120	12.28.2	DATASET2	DATASET1	3	1, 10, 17	49	76	6.6	2.7
121	12.28.3	DATASET2	DATASET1	3	1, 10, 17	96	87	26.1	43.0
122	3.2.1	ONEPAGE	TEST1PAGE	3	10, 19, 20	35	58	22.4	6.1
123	3.1A.1	ONEPAGE	TEST1PAGE	3	10, 14, 15	27	48	24.7	6.1
124	3.1A.2	ONEPAGE	TEST1PAGE	2	10, 14	34	61	24.3	6.1
125	3.1A.3	ONEPAGE	TEST1PAGE	2	10, 15	29	54	21.5	5.2
*	3.1A.4	ONEPAGE	TEST1PAGE	2	14, 15, no apparent separation	X	X	X	X
126	3.2.2	ONEPAGE	TEST1PAGE	2	10, 7	49	79	12.6	4.4
127	3.3.3	ONEPAGE	TEST1PAGE	2	5, 10	40	67	18.7	6.1
128	3.3.4	ONEPAGE	TEST1PAGE	2	3, 10	51	84	1[illegible].6	3.5

PLANE NO.	ID	ANALYSIS SET	TEST SET	# DIM	MEASUREMENTS USED	FALSE ALARM RATES ZONE 0	FALSE ALARM RATES ZONE 1	ERROR RATES ZONE 2	ERROR RATES ZONE 3
*	3.2.5	ONEPAGE	TEST1PAGE	2	4, 10, no apparent separation	X	X	X	X
129	12.28.4	DATASET2	DATASET1	2	1, 10	55	85	5.8	2.7
130	CALM.1	CALM1P	CALMR	12	1-7, 10, 11, 13, 14, 15	23	37	3.1	10
131	CALM.2	CALM1P	CALMR	12	1-7, 10, 11, 13, 14, 15	21	37	6.2	0
132	CALM.3	CALM1P	CALMR	12	1-7, 10, 11, 13, 14, 15	21	37	3.1	5.0
133	CALM.4	CALM1P	CALMR	12	1-7, 10, 11, 13, 14, 15	23	37	3.1	10
134	HEAD.1	HEAD1P	HEADR	13	1-7, 10, 11, 13, 14, 15, 20	31	61	12	6.7
135	HEAD.2	HEAD1P	HEADR	13	1-7, 10, 11, 13, 14, 15, 20	28	60	16	4.4
136	HEAD.3	HEAD1P	HEADR	12	1-7, 10, 11, 13 14, 15	33	65	12	6.7
137	HEAD.4	HEAD1P	HEADR	12	1-7, 10, 11, 13, 14, 15	13	42	28	13
138	FOLLOW.1	FOLLOW1P	FOLLOWR	13	1-7, 10, 11, 13 14, 15, 20	26	89	12	17
139	FOLLOW.2	FOLLOW1P	FOLLOWR	13	1-7, 10, 11, 13 14, 15, 20	23	57	22	25
140	FOLLOW.3	FOLLOW1P	FOLLOWR	12	1-7, 10, 11, 13 14, 15	29	86	12	11
141	FOLLOW.4	FOLLOW1P	FOLLOWR	12	1-7, 10, 11, 13 14, 15	35	69	16	19
142	FOLLOW.5	FOLLOW1P	FOLLOWR	2	10, 14	55	89	16	8.3
143	HEAD.5	HEAD1P	HEADR	2	10, 14	28	65	21	2.2
144	TURN.1	TURN1P	TURNR	13	1-7, 10, 11, 13, 14, 15, 19	37	82	11	15
145	TURN.2	TURN1P	TURNR	13	1-7, 10, 11, 13, 14, 15, 19	26	41	38	30

PLANE NO.	ID	ANALYSIS SET	TEST SET	# DIM	MEASUREMENTS USED	FALSE ALARM RATES ZONE 0	FALSE ALARM RATES ZONE 1	ERROR RATES ZONE 2	ERROR RATES ZONE 3
146	TURN.3	TURN1P	TURNR	12	1-7, 10, 11, 13, 14, 15	32	59	25	15
147	TURN.4	TURN1P	TURNR	12	1-7, 10, 11, 13, 14, 15	32	41	38	30
148	STR.1	STR1P	STRR	13	1-7, 10, 11, 13, 14, 15, 19	36	64	9.8	8.4
149	STR.2	STR1P	STRR	12	1-7, 10, 11, 13, 14, 15	30	58	13	8.4
150	STR.3	STR1P	STRR	2	10, 14	30	62	18	4.8
151	H.1	WHOLE SET	WHOLE SET	1	10	23	43	28	11
152	H.2	WHOLE SET	WHOLE SET	1	10	33	61	19	6
153	H.3	WHOLE SET	WHOLE SET	1	10	48	82	10	3
24*	12.2.1	CALM	STATES12	17	1-17	52	78	12	10
25*	12.2.2	CALM	STATES12	17	1-17	48	72	18	10
26*	12.2.3	CALM	STATES12	17	1-17	70	63	27	17
27*	12.2.4	CALM	STATES12	17	1-17	37	59	31	17
24*	12.2.1	CALM	whole data set	17	1-17	38	65	11	8
25*	12.2.2	CALM	whole data set	17	1-17	32	55	17	8
26*	12.2.3	CALM	whole data set	17	1-17	26	62	23	15
27*	12.2.4	CALM	whole data set	17	1-17	25	49	32	14

* Results for different data sets.

Description of Data Sets

NAME	DESCRIPTION	COUNTS Zone0	Zone1	Zone2	Zone3	TOTAL
WHOLE SET	Whole data set	152,	200,	276,	147;	775
DATASET1:	Concatenate Zone 0, 1, 2, 3, Select odd #'ed vectors	76,	100,	138,	74;	380
DATASET2:	Concatenate Zone 0, 1, 2, 3, Select even #'ed vectors	76,	100,	138,	73;	387
ONEPAGE:	Contains every 4th vector of Zone0, every 4th of Zone1, every 4th of Zone2, and every 4th of Zone 3	33,	44,	62,	32;	171
TEST1PAGE:	Complement of ONEPAGE within whole data set	119,	156,	214,	115;	604
P1STATES12:	Contains every 4th vector of STATES12 starting with 1st one	26,	34,	58,	31;	149
STATES12:	Contains all data points with sea state=1 or 2	101,	138,	233,	121;	593
CALM:	All points with sea state= "calm"	51,	62,	43,	26;	182
HEAD1P:	Concatenate Zone0, Zone1, Zone2, Zone 3 Select every 4th vector with param19, "heading," set to 1=HEAD	13,	18,	26,	15;	72
FOLLOW1P:	Same as HEAD1P but select every 4th vector with #19=3="follow"	10,	12,	22,	12;	56
CALM1P:	Same as HEAD1P but select every 4th w/#19=5="calm"	12,	16,	11,	6;	45

NAME	DESCRIPTION	COUNTS Zone0	Zone1	Zone2	Zone3	TOTAL
TURN1P:	Same as HEAD1P but select every 4th vector w/#20=1= "turn"	6,	6,	18,	9;	39
STR1P:	Same as HEAD1P but select every 4th w/#20=2="straight"	31,	45,	50,	28;	154
HEADR:	Complement of HEAD1P within #19="head"	39,	57,	76,	45;	217
FOLLOW1R:	Complement of FOLLOW1P within #19="follow"	31,	35,	68,	36;	170
CALMR:	Complement of CALM1P within #19="calm"	39,	46,	32,	20;	137
TURNR:	Complement of TURN1P within #20="turn"	19,	17,	55,	27;	118
STRR:	Complement of STR1P within #20="straight"	96,	132,	153,	83;	464
ZONES03	Zone0 and Zone3 data	152,	0,	0,	147;	299

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